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Lawrence Avenue Underflow Sewer System Interim Report: Planning and Construction

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Prepared for

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Cincinnati, OH

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Lawrence Avenue Underflow Sewer System

Interim Report Planning and Construction

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A new and bold concept in design of urban drainage systems was developed as a step forward in the solution of combined sewer overflow problems. A deep tunnel in bed rock about 200 to 250 feet (61 to 76 m) below the surface was designed and constructed for the Lawrence Avenue drainage basin in Chicago. Utilization of modern tunnel boring machines made the project economically competitive with conventional sewers while reaping additional benefits of ease in construction, no disturbance to traffic and least inconvenience to public. In addition, the tunnel sewer will serve as a reservoir totally capturing smaller storms, and trapping a significant portion of the first flush of pollutants from larger storms. The entrapped pollutional load will be pumped to a treatment plant through a pumping station to be operated only at the end of the storm, for dewatering the tunnel. The project is expected to reduce, to a large extent, the combined sewer overflows to the waterways.

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Interim Report
Planning and Construction

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Many of our cities are faced with pollution problems associated with combined sewer overflows. Reduction or elimination of combined sewer overflows into the receiving waters require some kind of storage and treatment facilities at considerable costs, particularly in large cities where land is scarce. Construction of deep rock tunnels to serve as main outlets for the combined sanitary and storm flow offers an attractive means of minimizing this problem. The sewer, being below the river level, provides storage and captures a large portion of the pollution from combined sewers. The construction cost of such a tunnel system brings some savings as compared to conventional surface sewers, because of the use of modern tunnel boring machines and the elimination of surface restoration costs. Moreover, the inconvenience to general public by disruption of streets, utilities, sidewalks, etc. and interference with commercial activity is completely avoided. This report describes the planning, design and construction of such a deep tunnel by the City of Chicago for their Lawrence Avenue drainage basin.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

A new and bold concept in design of urban drainage systems was developed as a step forward in the solution of combined sewer overflow problems. A deep tunnel in bed rock about 200 to 250 feet (61 to 76 m) below the surface was designed and constructed for the Lawrence Avenue drainage basin in Chicago. Utilization of modern tunnel boring machines made the project economically competitive with conventional sewers while reaping additional benefits of ease in construction, no disturbance to traffic and least inconvenience to public. In addition, the tunnel sewer will serve as a reservoir totally capturing smaller storms, and trapping a significant portion of the first flush of pollutants from larger storms. The entrapped pollutional load will be pumped to a treatment plant through a pumping station to be operated only at the end of the storm, for dewatering the tunnel. The project is expected to reduce, to a large extent, the combined sewer overflows to the waterways.

Hydraulic model studies were conducted at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, for the design of dropshafts to convey wet weather flows from surface sewers to the deep tunnel.

Pre-construction field measurements on the quantity and quality of combined sewer overflows have already been collected for a number of storms for 3 outfalls serving the Lawrence Avenue drainage basin. Similar measurements will be taken after the tunnel is in complete operation. Comparison of the results will be documented in a final report to demonstrate the effectiveness of this concept in reducing pollution to waterways from combined sewer overflows.

This report is submitted in partial fulfillment of Demonstration Grant No. 11020 EMD sponsorship of the U.S. Environmental Protection Agency.

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SECTION I

CONCLUSIONS

1. In planning new sewers for relief of existing sewer systems in large metropolitan areas served by combined sewers, due consideration should be given to utilize the storage in the sewer system, either by lowering the sewer profile below the level of receiving waters, or by some other means. This could greatly reduce spilling of pollution to the receiving waters by cutting down combined sewer overflows.

2. With the recently improved technology in the field of tunneling, a rock tunnel sewer, while being cost-competitive, promises certain advantages over a large conventional open-cut sewer. The former involves little interference with traffic, parking and commercial activity, least inconvenience to public, no hazards of accidental disruption of the numerous utility lines found in large cities and no costs of surface restoration.

3. Drilled tunnels utilizing rock boring machines (moles) are relatively smooth and need not be lined with concrete, if the rock is structurally sound and impermeable to exfiltration of polluted water into the aquifer. This would result in savings in lining costs and also add to the tunnel storage.

4. The air entraining dropshaft of the Type E-15, used for the Lawrence Avenue System, was found satisfactory through hydraulic model testing performed at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, for the purpose of dropping wet weather flows some 200 to 250 feet (61 to 76 m) from high level sewers to the deep tunnel. However, the sloping crown of the air collection chamber requires huge excavations with associated high costs, particularly for larger dropshafts than those built for the Lawrence Avenue Underflow Sewer System. Consideration should be given to reduce the size of the air chamber by venting air through a separate shaft wherever feasible. This was indicated by tests carried out

later at the St. Anthony Falls Hydraulic Laboratory in conjunction with development of dropshafts larger than 9 feet (2.75 m) diameter for the Tunnel and Reservoir Plan for the Metropolitan Sanitary District of Greater Chicago.

SECTION II

RECOMMENDATIONS

As a result of construction problems encountered in the field and additional hydraulic model studies undertaken in conjunction with our work with the Sanitary District, several recommendations for future "Underflow" sewers can be made as follows:

1. Specifications should require the use of a mole within all practical size ranges.

2. The drop shaft structures and the pumping station and outfall should be included in the same contract as the rock tunnel construction. This would give additional shafts for ingress and egress, and thus increase safety provisions. It would give the Contractor a greater number of locations where muck could be removed and would eliminate the interference of one Contractor with another.

3. The drop shaft structures should be simplified.

   a. Provide for slip forming shafts from top to bottom and thereby eliminate transition from inlet into circular barrel.
   b. Reduce the size of the air collector at the bottom of the shaft. In this area, consideration should be given to providing an additional smaller diameter shaft for air release.

4. A scale model of the pumping station and outfall should be provided by the designers as a check of the feasibility of the design features (and thus reduce the possibility of construction problems) and as an aid to prospective bidders.

5. The Contractor should be required to keep the floor of the tunnel cleared of muck and debris. Also, a better drainage system in the tunnel should be required. In this tunnel, walking any great distance was extremely difficult because of poor housekeeping.

SECTION III

INTRODUCTION

THE HISTORY OF TUNNELING IN CHICAGO STARTED WITH WATER TUNNELS

Chicago's first water tunnel was placed in service in March, 1867. The 5 foot (1.5 m) diameter brick tunnel, built in clay, about 60 feet (18.3 m) below lake level, and extending about 2 miles (3.2 km) into the lake to the Two Mile Crib intake was designed to supply Lake Michigan water to the City's first pumping station. It was considered a daring engineering project for its time and brought international fame to the City of Chicago.

As the City grew and its water works system expanded, additional tunnels were built to new pumping stations. However, many difficulties were experienced due to the poor soil conditions encountered. In an attempt to eliminate the hazards involved, City engineers resolved that, wherever feasible, future tunnels would be constructed in rock.

The first tunnel built in rock was the Southwest Lake and Land Tunnel, started in 1906 and completed in 1911. See Figure III-1. The depth varied from 102 feet (31 m) to 148 feet (45 m) for the land portion; the remainder was 160 feet (49 m) below lake level.

Mining in as many as six drifts was carried on simultaneously and progress varied in each. For the 14 foot (4.3 m) section the peak performance rate recorded by any one heading was 416 feet (127 m) in one month.

The standard method of top heading and bench was used in the mining operation. Blasting techniques left a lot to be desired with large areas of overbreak occurring, and conversely, considerable trimming was also required to permit construction of the desired section. The specified minimum thickness of the concrete lining was 12 inch (30.5 cm), 9 inch (23 cm) and 7 inch (18 cm) for the 14 foot (4.3 m), 12 foot (3.7 m) and 9 foot

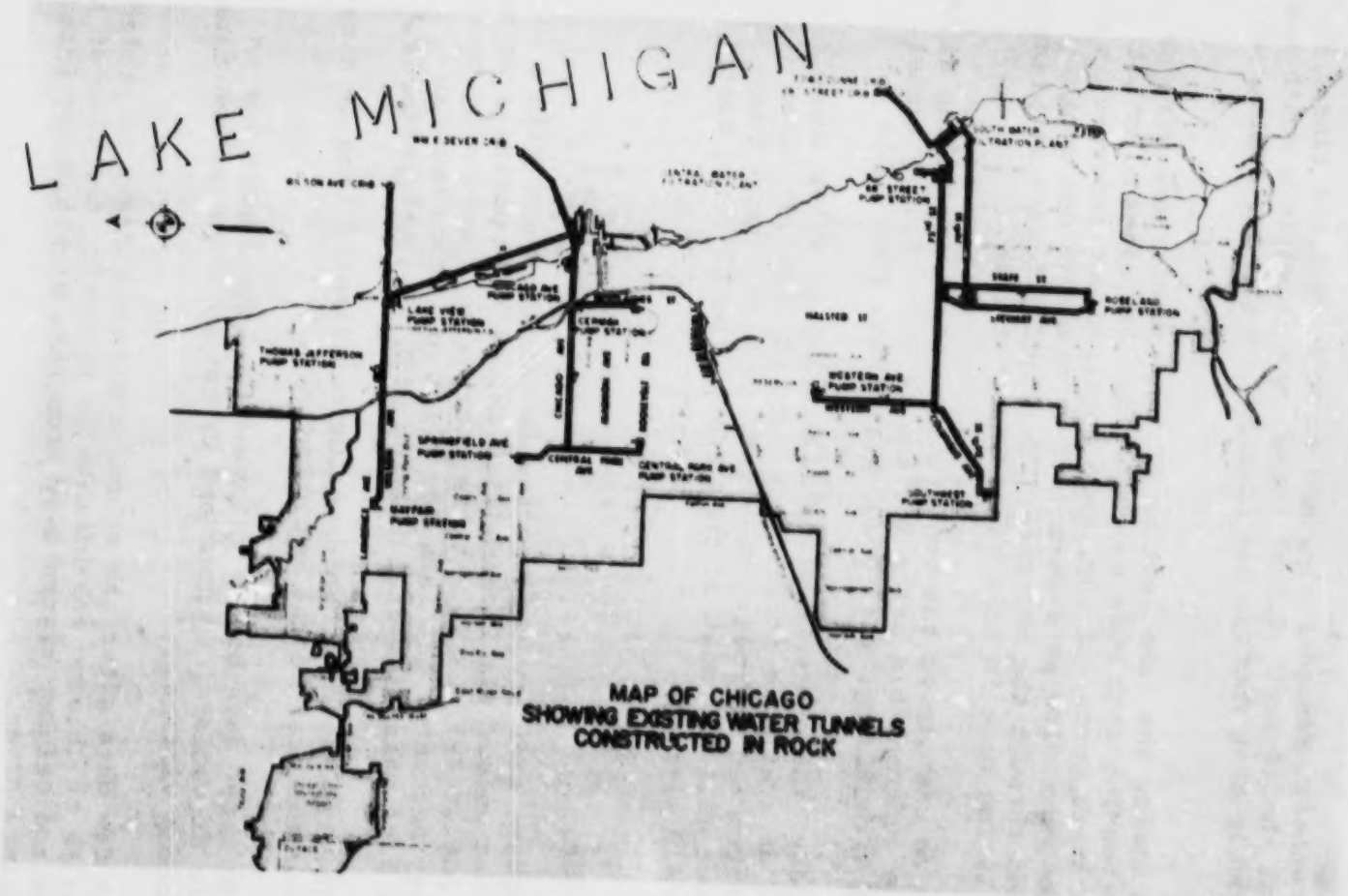


Figure III-1 Existing water tunnels constructed in rock

(2.7 m) tunnels respectively, and as much as 1,114 lineal feet (340 m) of the 14 foot (4.3 m) tunnel was lined in a month and almost double that footage was obtained in the two smaller size tunnels.

In mining the lake section of the tunnel, some stretches of water-bearing rock were encountered. Our records do not indicate what supports, if any, were required, but progress in one drift dropped as low as 4 feet (1.2 m) mined in one month. Water bled through the concrete lining and attempts at plastering the lining were in some cases almost futile.

As an example of the construction costs prevailing at that time, the contract bid price for the 14 foot (4.3 m) tunnel, complete with lining, was $79.00 per lineal foot ($260 per meter).

Today, there are 65 miles (104.6 km) of water tunnels in service, or available for service, and of these, 57 miles (92 km) were constructed in rock. They vary in size from 9 foot (2.7 m) to 20 foot (6.1 m), most of them are in the 12 to 16 foot (3.6 to 4.9 m) range.

STORMWATER

Modern sanitary engineering in Chicago began with a cloudburst that dumped six inches (15.2 cm) of rain during a 24-hour period August 2-3, 1885. At the storm's end, according to contemporary accounts, the lake for miles off shore was "an immense foul mass of wastes teeming with virulent bacteria."

The 1885 storm flushed pollution into the lake at a rate affecting the area to the water intakes.

In those days before chlorination, the result was an epidemic of cholera, typhoid and dysentery which proved fatal to numerous victims.

A few days after the storm, a plan was drawn to protect the health of Chicago inhabitants by reversing the flow of the Chicago and Calumet rivers away from Lake Michigan and into the Des Plaines River.

The Sanitary and Ship Canal was completed in 1900 and hailed as an engineering wonder of the world.

THE INTERCEPTING SEWER SYSTEM

The next step in the gigantic sanitation program involved sealing off all wastes from Lake Michigan; it was accomplished by constructing huge intercepting sewers 6 to 27 feet (1.8 to 8.2 m) in diameter. The intercepting sewers were linked to the City's system of collecting sewers. By 1907 the basic system had been completed and Chicago became the first Great Lakes city to stop using the lakes as a receptor of it's normal domestic sewage.

Because sanitation is a problem which extends beyond city limits, the Metropolitan Sanitary District of Greater Chicago (MSDGC) was established in 1889. The District was to provide for the collection and disposal of sewage from Chicago proper and the surrounding area and to prevent flooding by polluted water. Today the District serves an area of 860 square miles (2,227 sq. kms), 5,500,000 residents, and an industrial waste load equivalent to 4,500,000 persons.

When the Metropolitan Sanitary District grew by later annexations, other intercepting sewers were built along the lake shore. The North Shore Channel was built to bring fresh water from the lake at suburban Wilmette into the North Branch of the river. The total cost of the construction of the canals, sewers, locks, pumping stations and associated works of this drainage system was $125,091,977.

But, while improved waste treatment methods could deal with predictable problems, cloudbursts and flooding still remained.

The city's growth and multiplication of captured rainwater volume long since have exceeded the sewer system's capacity. On an average of 100 times a year, combined sanitary and storm water sewers overflow and surge into the rivers at 640 different points. Sometimes a mixture of stormwater and sewage backs up into thousands of basements. Twenty-one times in 30 years, flood gates of the Chicago and Calumet rivers have been opened to keep them from going over their banks.

THE CHICAGO UNDERFLOW PLAN

Recognizing the existence of many possible solutions to the problems of flood control and water pollution abatement, officials of the State, the County; the Metropolitan Sanitary District of Greater Chicago, and the City of Chicago formed a Flood Control Coordinating Committee.

After a thorough search of records and extensive investigation, twenty-three separate alternatives were identified for study. The system recommended was a composite of the several Underflow Plan Alternatives and was outstanding in its relative storage economy and simplicity and it was originally decided that this system will include 120 miles (193 km) of tunnels drilled principally through Silurian dolomite rock 150-300 feet (45.7-91.4 m) below the city's streets. The tunneling will be done underneath the rivers and the streets of the metropolis, thus avoiding the costs of acquiring new and expensive rights-of-way. Dropshafts leading to the tunnels will intercept the flow in 5,000 miles (8,045 km) of sewers before it can reach the 640 overflow points that now line the metropolitan river-canal complex. The tunnels will be drained by pumps associated with three storage reservoirs, by far the largest, of which will be a rock quarry 300 to 330 feet (91.4 to 100.6 m) deep. At maximum performance the quarry will hold a 200 foot (61 m) depth of water with a surface area 1,000 feet (305 m) wide and 2½ miles (4 km) long. To prevent odors, aerating pumps will continually agitate the wastewater prior to its being rationed out to sewage treatment plants. During these waiting periods, solids will settle to the quarry bottom and from time to time will be removed for use as fertilizer. This primary containing basin will be linked to the two smaller reservoirs, one of which is to be reserved for use only during the rare periods when downpours comparable to those experienced in the few peak hours of the worst rainstorm in Chicago's history may strain the system's capacity.

The tunnel and reservoir system will be a genuine flood control project as are the more customary dams and levees built by the Corps. For the tunnel and reservoir system would do more than eliminate both high flow velocity and low water levels in the Sanitary and Ship Canal; by breaking the force of a rainstorm, capturing the total rainfall, and later slowly releasing the water at a steady rate, the system would level out the canal flow while increasing the average water depth. See Figures III-2 and III-3.

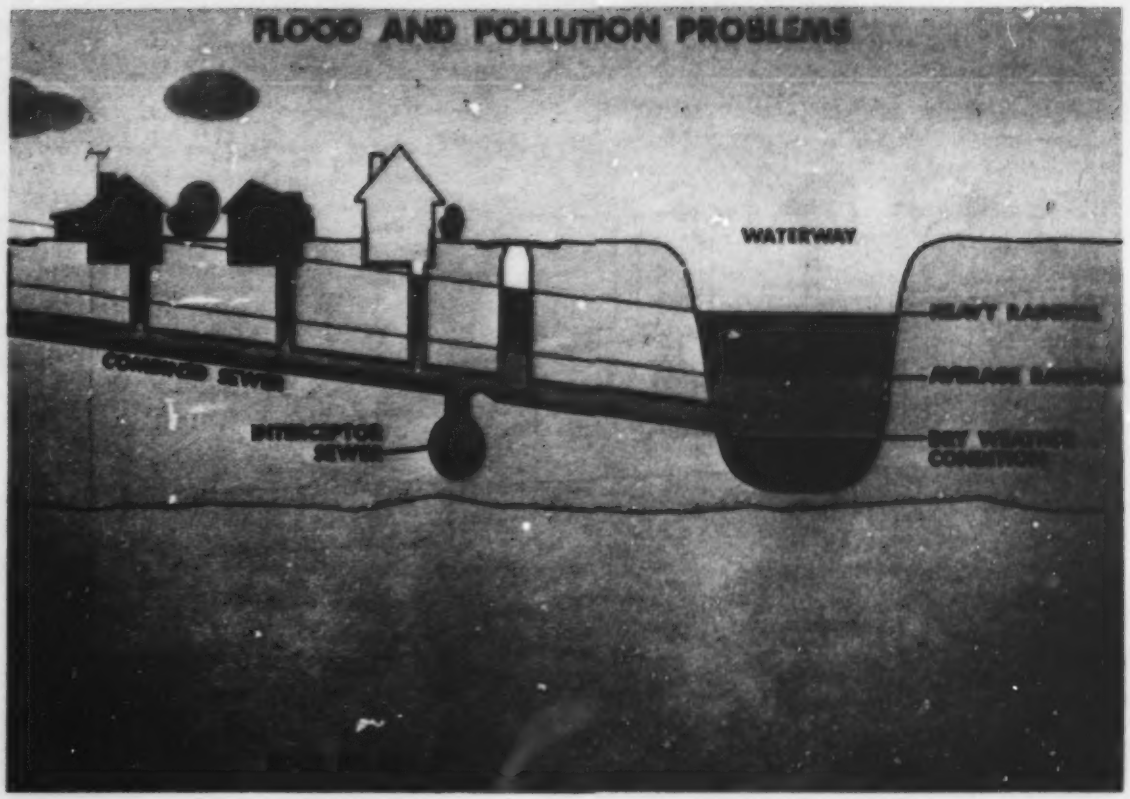


Figure III-2 Flood and Pollution Problems

Diagrammatic illustration of the present conditions: Dry Weather Condition - All dry weather flow is diverted into the interceptor sewer, and from there to an MSDGC sewage treatment plant. Average Rainfall - Some overflow is discharged into the waterway (river or canal), but the level is not high enough to affect basements or underpasses. Heavy Rainfall - The water level rises to a point where the hydraulic gradient reaches high enough to flood basements and depressed areas of the city.

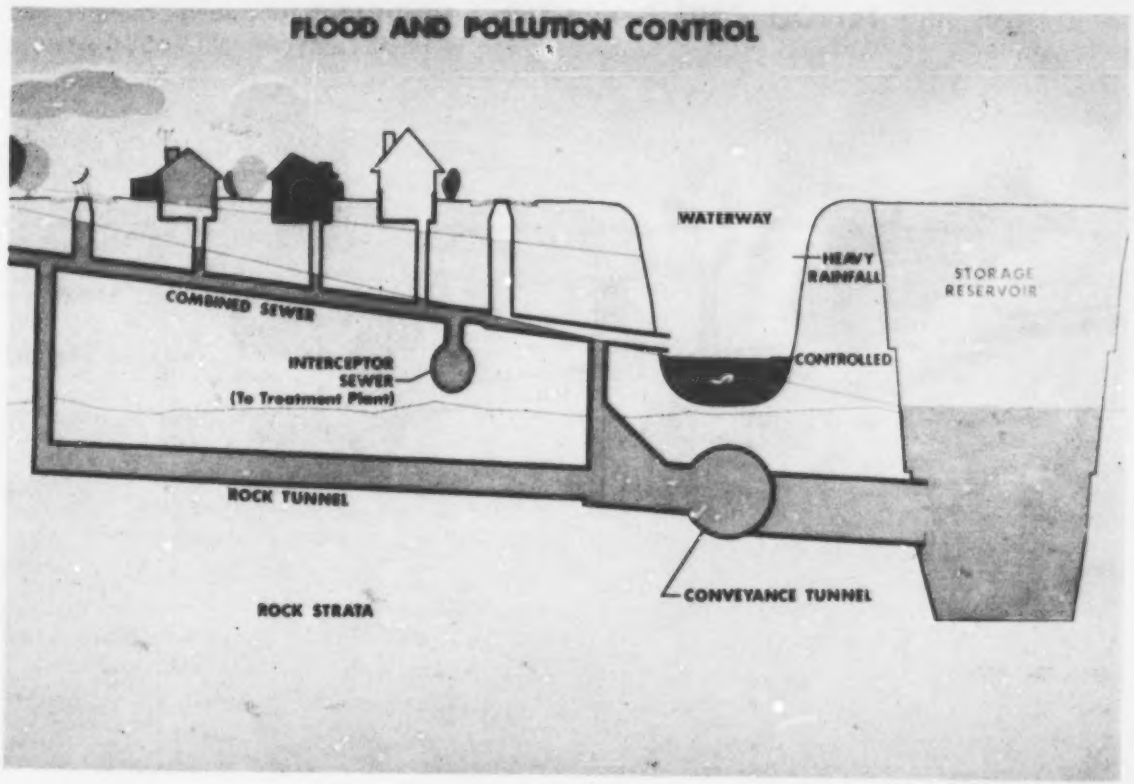


Figure III-3 Flood and Pollution Control

Diagrammatic illustration of the conditions after the "Tunnel and Reservoir Plan" is implemented: The water level is controlled by TARP during heavy rainfalls, overflow of combined sewage rarely discharges into the waterways and, the hydraulic gradient during heavy rainfalls does not affect basements and depressed areas. The heavy rainfall gradient is indicated to show conditions before TARP.

Completion of the Tunnel and Reservoir Plan is essential to the success of the late Mayor Richard J. Daley's "Chicago 21" scheme to stop deterioration of the central city and generate a vital new life style for the next century. The scheme covers only eleven square miles (28.5 sq. km)with a population of 165,000. But in this 5 percent of its area is one-third of the total valuation of the City's assessed property and 43 percent of all jobs available in the metropolitan area. By cleaning up the waterways that traverse the city, the Tunnel and Reservoir Plan will facilitate "Chicago 21's" intent to beautify the Chicago River environs so as to rival those of the Thames in London, the Seine in Paris, and the Arno in Florence.

MSDGC can use its own bonding authority to obtain part of the financing for the Tunnel and Reservoir Plan. Another part can come from other bonds already approved by the State of Illinois. But Federal appropriations guidelines set up in the 1972 amendments to the Clean Water Act of 1968 are clearly applicable to the Tunnel and Reservoir Plan. By the year 1983, the United States Environmental Protection Agency is charged with providing for the purification of all the nation's waterways to a degree that will encourage not only sailing, boating and fishing but also swimming. MSDGC's analyses show that the Tunnel and Reservoir Plan is the most reasonable and economical way to meet the EPA requirements. The plan will benefit much more than a single lake, albeit one of the Great Lakes. The ability to treat all, rather than only part of its sewage will enable any city now discharging sewage effluent into rivers or lakes within its boundaries to completely renovate its inner core.

The Lawrence Avenue Tunnel was the first section of the Chicago deep tunnel to be constructed, and as such will be described in detail in this report.

SECTION IV

LAWRENCE AVENUE UNDERFLOW SEWER SYSTEM

GENERAL DESCRIPTION

Under the City of Chicago's Auxiliary Outlet Sewer Programs, started in 1947, more than 230 miles (370 km) of new large sewers have been constructed or are under contract at a total cost of $203,000,000. The passage of the Sewer Bond Referendum of July 7, 1977 will add another 23 miles (37 km) of sewers to be constructed at a cost of $30,000,000. The remainder of the City's present Five Year Capital Improvements Program provides for the construction of an additional $116,000,000 of new outlet sewers. When these sewers have been constructed all community areas in the City will have received benefit.

In 1963, the City of Chicago's Five Year Capital Improvements Program called for the construction of a new Auxiliary Outlet Sewer System to provide relief from basement and underpass flooding of an area bounded by the North Branch of the Chicago River, Irving Park Road, Oriole Avenue and Devon Avenue. See Figure IV-1. Preliminary hydraulic studies indicated that a new trunk sewer in the vicinity of Wilson Avenue from the North Branch of the Chicago River to Melvina Avenue with branches extending north and south to intercept existing trunk sewers, would provide the necessary flood relief.

This proposed sewer system was designated the Eastwood-Wilson Avenue Sewer System and varied in size from a 2 barrel 13 ft. (3.96 m) by 13 ft. (3.96 m) section at the lower end near the River to a 7.5 ft. (2.29 m) circular section at its upper end. This sewer was proposed to be built in five contracts, by conventional methods, four by open cut construction and one by earth tunnel under the Edens and Kennedy Expressways. See Plan and Profile, Figure IV-2.

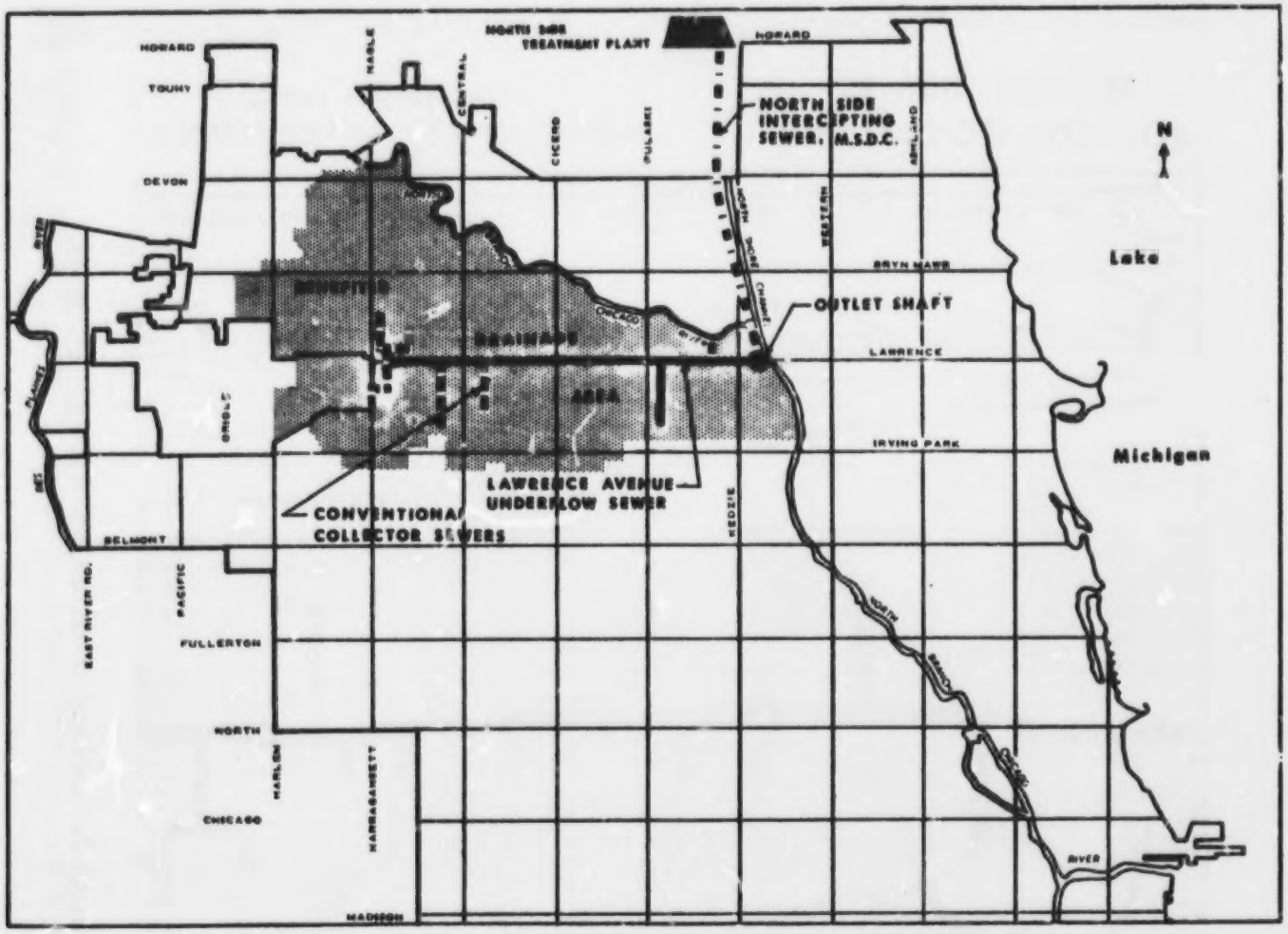


Figure IV-1 Proposed Eastwood-Wilson Sewer System Location Map

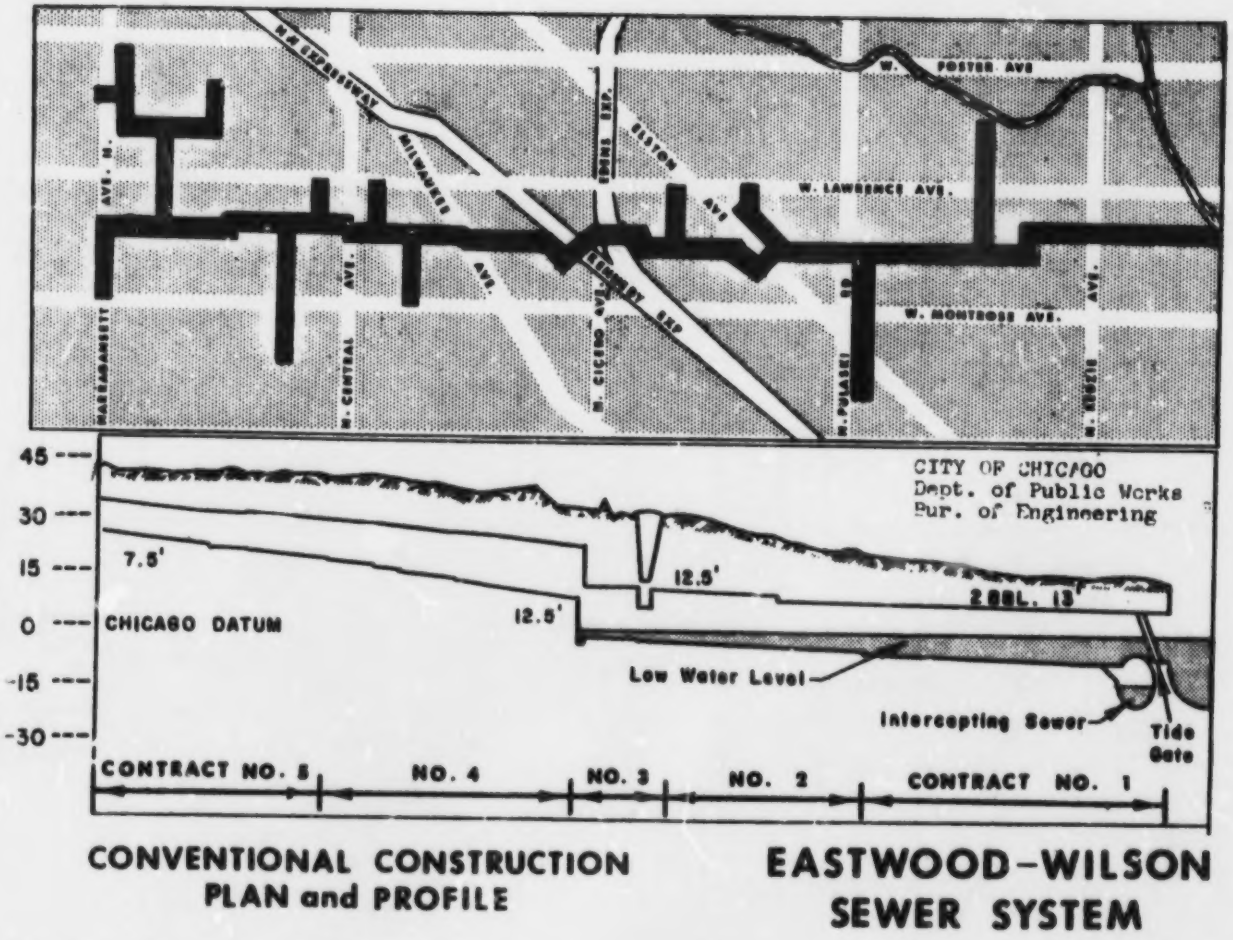


Figure IV-2 Plan and Profile of Proposed Eastwood-Wilson Sewer System

Some measure of reduction in pollution, caused by the overflow from combined sewers to the river, is provided by depressing the outlet of the conventional auxiliary outlet sewers below river level. The resulting storage thus produced is sufficient to contain the runoff from frequently occurring small rainfalls and thus preventing overflows to the river. The Eastwood-Wilson Avenue sewer system would have equivalent storage volume below low river water level of 0.07 inches (0.18 cm) spread over its 3620 acre ($14.6 \times 10^6 m^2$) direct tributary drainage area. This would be equal to the runoff from a mass rainfall of approximately one quarter of an inch (0.63 cm) over this entire area.

Because pollution abatement was of major concern to engineers in this field, consideration was given to lowering the profile to increase the pool storage available in the downstream end of the sewer and thereby reduce the frequency of overflows from this combined sewer to the river. Lowering the profile would necessitate pumping of sewage to the existing sanitary intercepting sewer, increasing the overall cost. It would also require that more of the construction be performed by earth tunnel method. Recent development of earth mining machines has resulted in lower bid prices in earth tunnel contracts. However, preliminary soil investigations indicated that heavy primary steel lining and occasional rock sections would negate the savings from the use of such machines. Costs would greatly exceed that of the conventional open cut construction method.

The City of Chicago had obtained previous experience in building large water tunnels in rock at an elevation of 100 feet (30.5 m) to 200 feet (61 m) below the surface, i.e., the 6 mile tunnel under Lake Michigan from the Central District Filtration Plant to Wilson Avenue, a 4.6 mile (7.4 km) tunnel in 79th Street, and the 3 mile (4.8 km) tunnel in Columbus Avenue. These tunnels ranging in size from 12 feet (3.6 m) to 16 feet (4.9 m) were constructed by the conventional drill and blast method.

Recent improvements of the rock mining machines (Moles) had reduced the cost of tunneling in various kinds of rock materials for large irrigation and hydroelectric projects throughout the world. Preliminary cost estimates revealed that mining in rock might be competitive with open cut methods.

Lowering the profile of the Eastwood-Wilson sewer over one hundred feet into bed rock looked promising. Sanitary flow would not normally, in dry weather periods, enter the tunnel

and therefore would not be pumped on a continuous basis. Pumping would be required, however, for dewatering of the tunnel to the existing sanitary intercepting sewer in the post rainfall period.

The City of Chicago's Department of Public Works retained the services of a consulting engineering firm, Harza Engineering Company, to study alternate methods of constructing the proposed Eastwood-Wilson Auxiliary Outlet Sewer System. The studies included a comparison of costs of constructing the sewer by open cut and tunnels, the hydraulic feasibility of the system, the maintenance and operating costs, and recommendations on the best method to fit the City's needs.

Beginning November 1, 1966 the sewer project known as EASTWOOD-WILSON was re-designated as the LAWRENCE AVENUE SYSTEM with subsequent contracts prepared by the Harza Engineering Company. The principal sewer, Contract No. 1, was designed and built in deep tunnel as recommended in the appraisal report prepared by said firm.

A review of geologic data indicated that, along the proposed route of the rock tunnel, the stratigraphic sequence would start with an overburden of glacial drift varying in thickness of Niagaran-Alexandrian rock lying above a formation of Maquoketa shale. It was the Niagaran-Alexandrian rock strata which warranted more information. Thirteen borings were taken along the route to a depth exceeding 250 feet (76 m). The analysis of these borings was studied with three elevation ranges in mind. The upper range contained interbedded cherty and shaly dolomite with some zones of reef material. If built in this range, the tunnel would be located within 40 to 50 feet (12 to 15 m) of depressions in the bedrock surface which was known to be locally broken and fractured. It was thought that clay-filled crevasses might be present as had been observed at quarries in the Chicago region and as encountered in water tunnel rock mining in nearby Wilson Avenue. Also, the weathered rock occurring at the top of bedrock contained open joints and solution channels and was known to be a high-yielding groundwater aquifer.

If the tunnel were constructed in the middle range, it would pass predominately through a porous dolomite believed to have originated as a coral reef. "Drillability" tests of typical core samples taken from the Lawrence Avenue borings brought forth an opinion that the reef dolomite had a drillability of

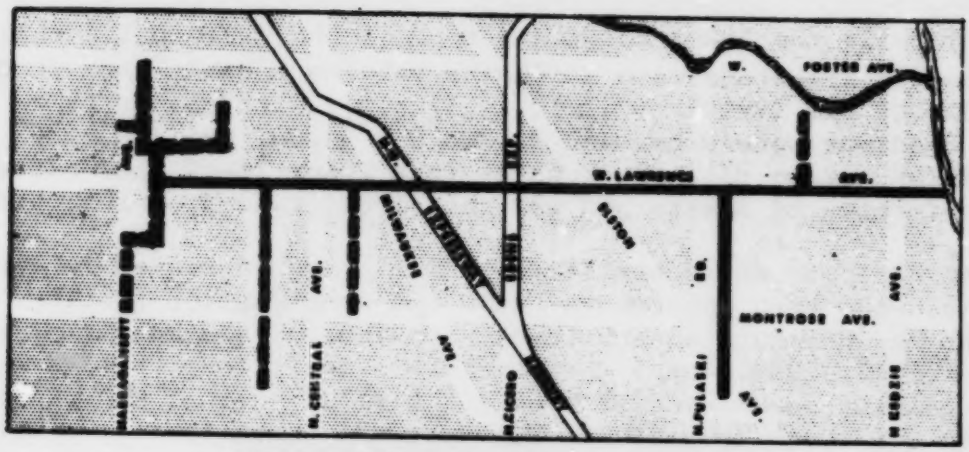
about 25% less than the other types of rock tested.

The rock in the lower range was found to be principally shaly dolomitic limestone with strengths varying roughly from 10,000 to 30,000 psi ($7x10^6$ to $21x10^6$ kgs/sq m), with the majority of the readings spread between 19,000 and 23,000 psi ($13.4x10^6$ and $16.2x10^6$ kgs/sq m). The rock at this lower level also presented a uniformity of strata and was relatively free from interbeds.

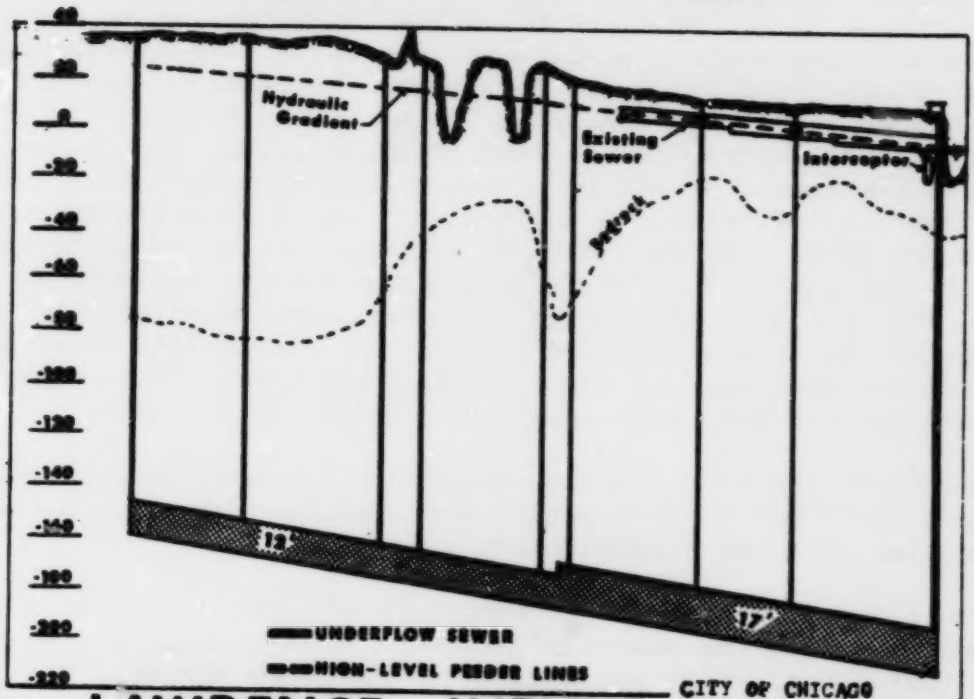
These geologic characteristics, which are only stated in general terms, were then related to costs and construction problems that might be inherent to each level. Obviously, the more shallow the tunnel, the greater the savings in shaft construction costs and pumping requirements, both in original cost of the pumping units and their operation. However, the porosity of the upper level rock, with clay-filled crevasses and the possibility of fractured rock zones could result in costly and hazardous construction with the need for steel roof supports, as well as rock bolts and wire mesh, and would require that a substantial concrete lining be installed. Because of the negative features of the higher level rock zone plus the necessity of crossing a water tunnel located in the same stratum, it was decided to locate the tunnel at a depth ranging from 250 feet (76 m) to 220 feet (67 m) below the surface. It was also believed that, with the dense, uniform dolomite to be found at the accepted level, any possibility of polluting the aquifer would be eliminated and that as construction proceeded, evidence would be gathered and a determination made on the possibility that, where mining was performed by machine, no lining would be required, or at the most, a very thin lining for hydraulic reasons.

Where drill and blast methods were used for rock excavation, an 8-inch (20.3 cm) minimum lining was specified because of the irregular surfaces typical of this procedure.

Harza's appraisal report recommended the construction of a lined tunnel sewer in the Niagaran limestone formation approximately 250 feet (76 m) under the surface of Lawrence Avenue. See Figures IV-3 and IV-4. The rock tunnel would be excavated by a tunnel boring machine. The Lawrence Avenue route was selected because of the requirement of the mole to travel in nearly a straight line. Because the tunneling would be so far below the surface, traffic in that arterial street and commercial activities would not be interrupted, as would be the case with the conventional open cut construction.



UNDERFLOW PLAN



LAWRENCE AVENUE UNDERFLOW TRIBUTARY

CITY OF CHICAGO
Dept. of Public Works
Bur. of Engineering

Figure IV-3 Lawrence Avenue Underflow Sewer System Location Plan and Profile

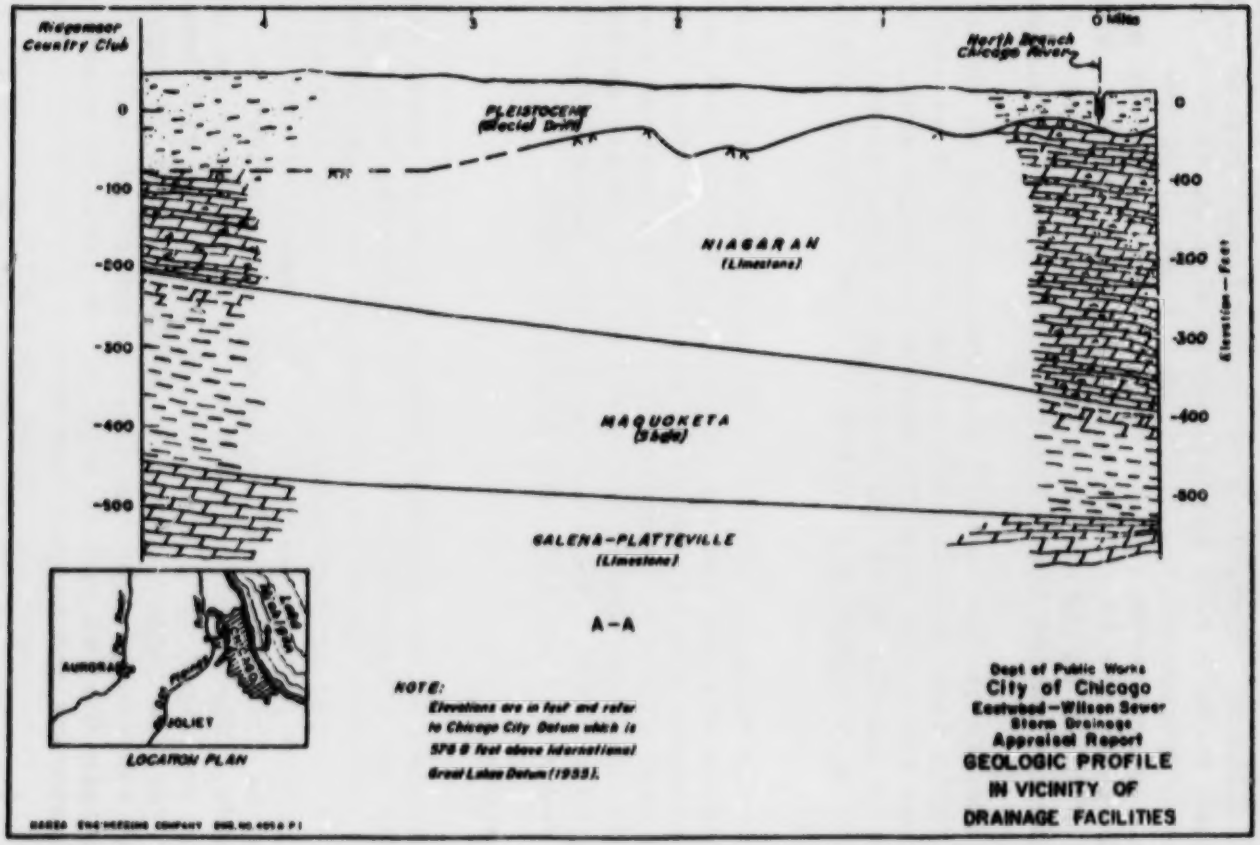


Figure IV-4 Geologic Profile in Project Vicinity

The main tunnel would be 12,800 feet (3091 m) long at 12 feet (3.7 m) in diameter and 9,300 feet (2835 m) long at 17 feet (5.2 m) in diameter. A branch tunnel in Harding Avenue extending south from Lawrence Avenue to Berteau Avenue, a distance of 4,000 feet (1219 m) (formerly a new conventional branch line, later lowered to be a rock tunnel) would also be 12 feet (3.6 m) in diameter. Approximately 18,000 feet (5486 m) of new conventional branch sewers would relieve the overloaded existing sewers and convey the flow to the tunnel inlet shafts. Ten inlet shafts would be constructed to supply the tunnel and one 30 foot diameter outlet shaft for the discharge of drainage.

The total storage in the tunnels and shafts would be about 4,000,000 cubic feet (113,280 m^3) or about 0.30 of an inch (0.8 cm) over the 3,620 acre (14.6×10^6m) drainage area. This storage would provide space for the runoff from rainfall accumulation up to about 0.9 inches (2.3 cm) without overflowing to the river.

The cost of the tunnels, shafts, high level collecting branch sewers, pumping and ventilation facilities and the gate and outfall structures was estimated at $12,334,000. This was $2,000,000 less than the estimated $14,350,000 cost of the conventional open cut method of construction. These estimates were prepared in 1966. The Engineering News Record, Construction Cost Index at that time was about: ca 1019.

COMPUTER STUDIES

In order to analyze the Lawrence Avenue Underflow sewer system under actual operating conditions, a mathematical model of the system was simulated in a computer program developed by the City of Chicago's Bureau of Engineering. Each hour of rainfall during an entire year was analyzed. The amount of rainfall along with the corresponding hourly code was recorded on punched cards. The computer was programmed to determine the net runoff from the impervious and pervious areas for each hour of rainfall. For the impervious area, a small amount of depression storage was subtracted from the first hours of rainfall of each storm to obtain the net runoff supply. On pervious areas, depression storage and varying amounts of infiltration depending on wet or dry antecedent conditions were subtracted from the rainfall to determine the net runoff supply. The total runoff was then calculated by weighing the net runoff supply from the impervious and the pervious areas in accordance with the imperviousness ratio of the tributary drainage area.

A hydrograph with a mass equal to the net runoff supply was then developed. The base of this hydrograph can be caried for the time of concentration of the tributary sewer system. The hydrographs for adjacent hour periods having a net runoff supply were then added together, somewhat similar to the method used in summing the unit hydrographs in river hydrology.

Sanitary flow at a rate of 100 gallons (378.5 liters) per day per capita was added to these runoff hydrographs to obtain the combined flow hydrographs for every rainfall period of the year. For this study 0.01 cubic feet per second per acre (7.07×10^{-4} cubic meter per second per hectare) was used as the sanitary flow rate. This rate has been verified as a good approximation for the quantity of sanitary flow by the U.S. Public Health Service studies on the Roscoe Street sewer system.

At each overflow point of the existing sewer system, it was assumed that up to two times the dry weather flow would continue to flow by the overflow weir and along its present route to the treatment plant. The excess flow over and above two times the dry weather flow overflows down into the tunnel system.

The sanitary flow at these overflow points is assumed to be uniformly mixed in the total combined flow upstream of the controlling weir. Four assumptions were set for the pollutional load in the combined flow. These were as follows:

1. Suspended Solids in Sanitary Sewage = 114 mg/l
2. Suspended Solids in Stormwater Runoff = 227 mg/l
3. B.O.D. in Sanitary Sewage = 96 mg/l
4. B.O.D. in Stormwater Runoff = 17 mg/l

Data for sanitary sewage were taken from the Metropolitan Sanitary District records of influent to the North Side Treatment Works for the years 1958 and 1959. Data for storm flow were taken from a report of stormwater runoff measurement by the Public Health Service for a test drainage area in Cincinnati, Ohio.

A graph of the storage volume was plotted against the water surface elevation in the tunnel. This data was placed in the computer with linear interpolation between sets of points. When the volume of inflow to the tunnel exceeded the total storage volume, the excess water was discharged to the river. Limitations were placed on the maximum discharge flowing through the system, since storms exceeding the design capacity of the

existing sewer system and the new tunnel system would cause upstream basements to flood. This flooding would limit the maximum discharge through the system. This eventuality was provided for in the computer by flood routing procedures and limiting the maximum discharge to 1500 cfs (42.48 m^3 per second) to cover a storm event with a return period of 5 years.

A set time after the last hour of rainfall of a storm period, the dewatering pumps were turned on. The pumps were set at 48 cubic feet per second (1.36 m^3 per second) which would provide complete dewatering of the tunnel to the interceptor in 24 hours.

The B.O.D. in the tunnel was assumed to be pumped to the interceptor or to overflow to the river at the instantaneous concentration in the system. The suspended solids were divided into two parts, that which would remain in suspension and that which would settle as a function of tunnel velocity. That portion which remained in suspension was pumped during dewatering or overflow to the river at the instantaneous concentration in the system. The volume of suspended solids that settled to the bottom was assumed to be removed by flushing and pumping after the tunnel was dewatered, or during large storms when high velocities occurred in the tunnel and scouring would cause the settled solids to be washed to the river. A linear relation between zero resuspension for zero velocity to 100% resuspension for a velocity of 10 feet per second (3 m per second) was used.

The type-out of the computer program was as follows:

Column	Description of Data
1.	Time in hours from beginning of year.
2.	Rate of rainfall for hour period.
3.	Runoff in cubic feet per second from the drainage area.
4.	Instantaneous elevation of water surface in tunnel.
5.	Volume of water in the tunnel, in cubic feet.
6.	Discharge into the tunnel, in cubic feet per second.
7.	Pumping rate to M.S.D. interceptor, in cubic feet/second.
8.	Overflow from tunnel to river, in cubic feet/second.
9.	Accumulation from first of year of suspended solids to tunnel, in pounds.

Column (contd)	Description of Data (contd)
10	Accumulation from first of year of B.O.D. to tunnel, in pounds.
11	Accumulation from first of year of suspended solids to river, in pounds.
12	Accumulation from first of year of B.O.D. to river, in pounds.
13	Accumulation from first of year of suspended solids pumped, in pounds.
14	Accumulation from first of year of B.O.D. pumped, in pounds.

In Columns 9 & 10, the suspended solids and B.O.D. overflowing the weir to the tunnel can be assumed to be equivalent to the spillage to the river of an existing sewer system of equivalent drainage area. Therefore, comparing these columns with Columns 11 and 12 enables the determination of the reduction in suspended solids and B.O.D. for the drainage area with the Lawrence Avenue tunnel system in place.

Table I, see Figure IV-5, shows the results summarized for five years of records using the rainfall as it occurred at Midway Airport, U.S. Weather Bureau Gage for 1956 to 1960 inclusive.

Table I

PERFORMANCE COMPARISON
LAWRENCE AVENUE UNDERFLOW SEWER - EXISTING CONVENTIONAL SEWERS IN AREA

A Summary of Computer Calculations Based on Hourly Precipitation Records for 5 Years Period 1956 - 1960

CRITERIA		1956	1957	1958	1959	1960	5 Year Average
HOURS OF PRECIPITATION		446	631	456	631	547	542
TOTAL PRECIPITATION (Inches)		22.23"	44.29"	26.35"	38.68"	27.84"	32"
EXISTING CONVENTIONAL SEWERS IN AREA OVERFLOW TO RIVER	Number	52	79	55	61	47	59
	Duration (Hrs.)	156	336	183	282	218	235
	Suspended Solids (Lbs.)	557,400	1,882,500	840,900	1,406,100	877,700	1,112,900
	B.O.D. (Lbs.)	81,600	236,000	114,700	182,700	124,200	147,800
LAWRENCE AVENUE UNDERFLOW SEWER OVERFLOWS TO RIVER	Number	4	6	6	4	6	5
	Duration (Hrs.)	9	22	17	15	25	18
	Suspended Solids (Lbs.)	73,600	763,300	156,200	542,300	199,400	347,000
	B.O.D. (Lbs.)	11,300	75,900	20,300	52,000	25,100	36,900
REDUCTION (Percent) IN OVERFLOWS DUE TO LAWRENCE AVENUE UNDERFLOW SEWER	Number	92%	92%	89%	93%	87%	91%
	Duration (Hrs.)	94%	93%	91%	95%	89%	92%
	Suspended Solids (Lbs.)	87%	60%	81%	61%	77%	73%
	B.O.D. (Lbs.)	86%	68%	82%	72%	80%	78%
MAXIMUM STORAGE TIME IN TUNNEL - STARTING DEWATERING PUMPS 4 HOURS AFTER RAINFALL (PUMP CAPACITY - 48 CFS)	Hours	87	70	63	68	89	75
	Days	3.6	2.9	2.6	2.8	3.7	3.1

Prepared by:
The City of Chicago, Department of Public Works, Bureau of Engineering

Figure IV-5 Performance comparison table of computer calculation summary for Lawrence Underflow vs. Existing Conventional Sewers

SUMMARY OF THE LAWRENCE AVENUE SEWER SYSTEM

A chronology of events leading up to the development of the Lawrence Avenue Sewer Plan including the appraisal report by the Bureau of Engineering's consultant, Harza Engineering Company, and the electronic computer studies is presented.

The appraisal report recommended the Lawrence Tunnel Sewer with indicated savings of $2,000,000 over the conventional open cut method while providing all of the benefits of flood protection. It minimized street disruption during construction and resulted in less inconvenience to residents, pedestrians, commerical enterprises, parking, vehicular traffic and utilities. The Underflow Sewer would result in greater storage and provide for less frequent overflows to the Chicago River.

The computer studies summarized in Table I indicate an average of the five years studied of 59 overflow periods for a total of 235 hours for the existing sewers and would be reduced to 5 overflow periods for a total of 18 hours. This represents an average of about 92 percent reduction in both the number of overflow periods and the hours of overflow. The pounds of suspended solids and B.O.D. discharged to the river would be reduced by 73 and 78 percent, respectively.

Studies have indicated that combined sewers spill in the neighborhood of 3% of the sanitary sewage to the receiving streams during the course of the year. The above figures indicate that with the Lawrence Avenue Underflow Sewer in operation, less than 0.8% of the sanitary sewage pollutants would be discharged to the North Branch of the Chicago River from its tributary drainage area. Another way of stating this is to say that over 99% of the suspended solids and B.O.D. contained in sanitary sewage would be delivered to the treatment plant for processing before being discharged to the waterways.

In the pumping station contract, instrumentation was to be provided to monitor the gate openings, the level of water in the tunnel at all times, operation of the dewatering pumps and automatic sampling during spillages to the river.

It was hoped that construction under the first contract would demonstrate that the use of a hard rock mining machine or "mole" to tunnel through the hard dolomitic limestone rock in the Niagaran strata was economically feasible and would provide data for future sewers of this type.

FEDERAL GRANT (EPA Grant No. 11020 EMD)

Early in 1967, the Department of Public Works applied for a Federal Demonstration Grant for the Lawrence Avenue Deep Tunnel Sewer System. A grant offer of $1,500,000 was approved on April 25, 1967, subject to the approval of final plans and specifications for the project in addition to other conditions and assurances.

It was considered to be a demonstration grant because no city in the nation was currently using such a system, which would have application in highly developed urban areas where space for surface storage is uneconomical. The portions of the project which were eligible for grant participation, however, were limited to the rock tunnel sections and the pumping facility under Contracts No. 1 and No. 3.

PREPARATION OF CONTRACT DOCUMENTS

Based on the findings of the appraisal report, the City's Department of Public Works, retained Harza Engineering Company to prepare contract documents for the Lawrence Avenue System. The total cost of this consulting contract was $621,142.00 which included the appraisal report, reimbursable items, and services provided in the design and preparation of contract documents for the following contracts, construction of which were required to complete the system as planned:

Contract No. 1 - Main Shaft and Rock Tunnels
Lawrence Avenue Monitoring Wells
Contract No. 2-A - High-Level Tunnels in Earth
Contract No. 2-B - Ten Drop Shafts
Contract No. 3 - Pumping Station and Outfall
Contract No. 4 - Additional High-Level Sewers

CONSTRUCTION PROGRESS

Contract No. 1

Main Shaft and Rock Tunnels

Contractor: Joint venture of James McHugh Construction Company, S.A. Healy Company, and Kenny Construction Company.

Bid Price: $10,792,094.00

Financing: 22% of construction cost was paid from City's share of Motor Fuel Tax Funds. Balance from Sewer Bond Funds, and from Federal Funds.

Location: In Lawrence Avenue from North Branch of the Chicago River to Melvina Avenue, and in Harding Avenue from Lawrence Avenue to Berteau Avenue.

Contract Description: 16,638 feet (5,071 m) of 12'-0" (3.66 m) diameter and 9,126 feet (2,782 m) of 17'-0" (5.18 m) diameter concrete-lined sewer tunnels in rock; excavation of approximately 250 feet (76.2 m) of main shaft of 29'-0" (8.84 m) in diameter in earth excavation and 27'-0" (8.23 m) in diameter in rock excavation; surface restoration; and all appurtenant and collateral work.

Construction Starting Date: November 6, 1967

Status: Contract completed May 28, 1973

Construction Methods:

As a prebidding feature, DPW had in February of 1967 advertised an invitation notice to inform prospective bidders of the work to be done under this contract. At the conference that followed, and which was attended by representatives of almost fifty contracting, manufacturing and supply companies, it was indicated by the City that consideration should be given to boring the rock tunnels by machine if possible.

The low bidder on this project elected to use an existing rock mining machine that could be made available in a short time but whose cutting-face diameter was 13'-8" (4.17 m). His procedure called for first mining the 17-foot (5.18 m) tunnel with this machine at the correct bottom elevation and then enlarging to proper size by conventional drill and blast methods. By mining

to the correct bottom elevation, trackage for his muck cars could be installed and put into use as the heading advanced.

The 12-foot (3.66 m) finished diameter tunnel in Harding Avenue and in Lawrence Avenue (west of Kildare Avenue) would also be bored with this machine. Both size tunnel sections would be lined with a minimum 8" (20.3 cm) concrete lining as specified in the contract documents.

The Contractor started work by excavating the main shaft with conventional methods. See Figure IV-6. The top forty feet (12.2 m) of 29 foot (8.84 m) diameter shaft in over-burden was supported by steel ribs and sheeting. The additional 215 foot (65.5 m) depth of shaft, 27' (8.23 m) in diameter, was drilled and blasted in a very short time. A tail tunnel, see Figure IV-7, to accommodate muck car unloadings, was blasted for a distance of 73 feet (22.25 m) northeasterly from the shaft, and a 316 foot (96.3 m) length of full-size excavation for the 17-foot (5.18 m) tunnel section was shot out while waiting for the mining machine to be delivered.

The rock-mining machine, see Figures IV-8, IV-9 and IV-10, was assembled in the tunnel and, for the next two months, tested under actual operating conditions until the Contractor was satisfied that limestone of the hardness of 11,400 psi to 29,600 psi ($8x10^6$ kgs/m^2 to $21x10^6$ kgs/m^2) that was expected to be encountered could be successfully bored by Machine. Several types of conveyor set-ups were also tried during this time in an attempt to find an efficient way of bringing the muck from the cutting wheel to the cars. The excavated material as cut by the machine resembled irregular chips of rock, no longer than 2" (5.1 cm) on any side. A substantial amount of muck was too fine in size to be scooped up by the machine and had to be washed out from in front of the machine face.

The tunnel was properly ventilated as work progressed, and for dust control, water was sprayed on the rock face at the heading at a rate of 40 gpm (151.4 l/m).

All tunnel excavation then stopped for 39 calendar days while the Contractor erected his head frame and hoisting equipment, see Figure IV-11, and performed other miscellaneous work. At the end of May, 1968 full scale use of the mole began.

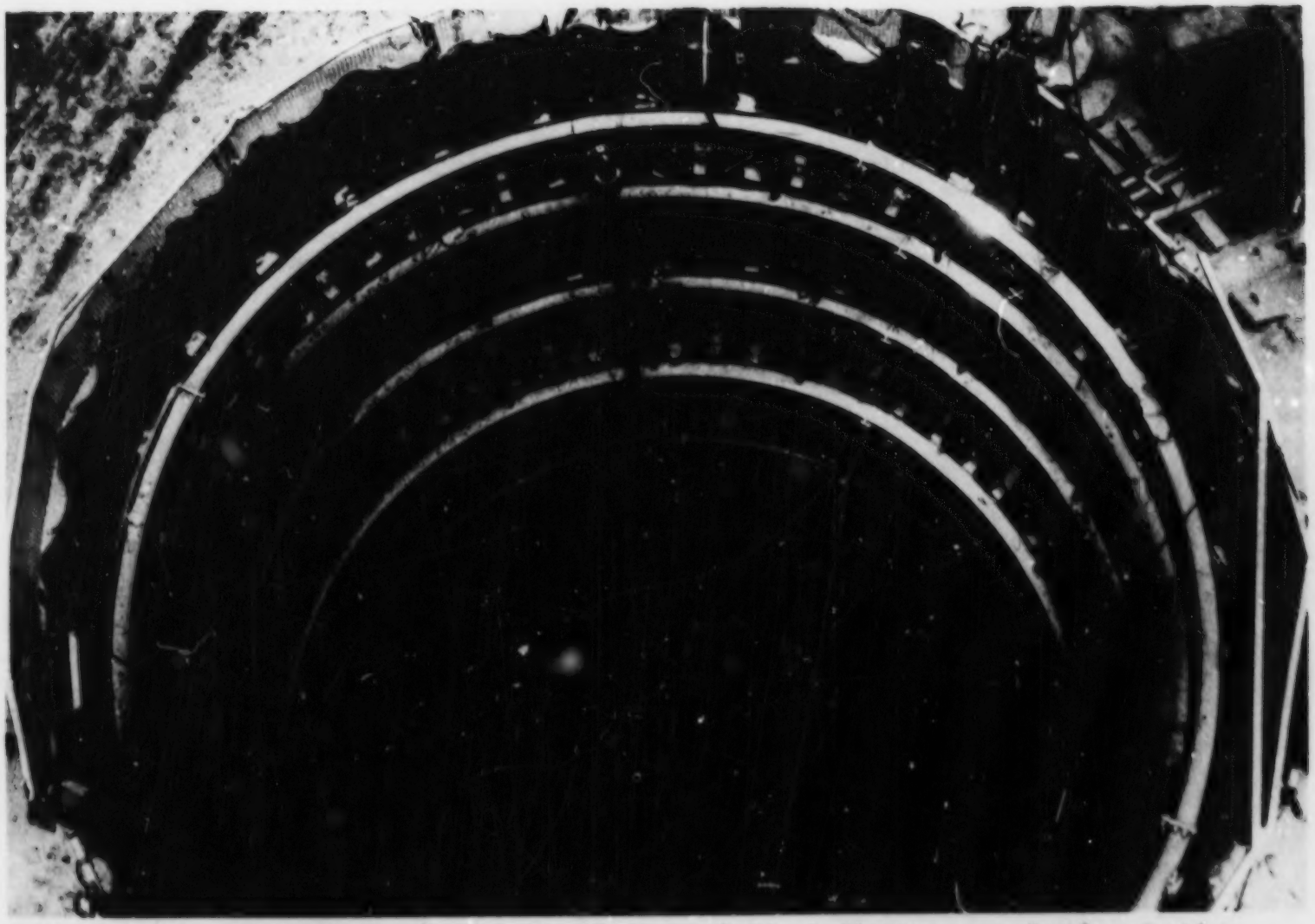


Figure IV-6 Main shaft showing the 29 foot (8.84 m) diameter overburden section supported by steel ribs and sheeting.

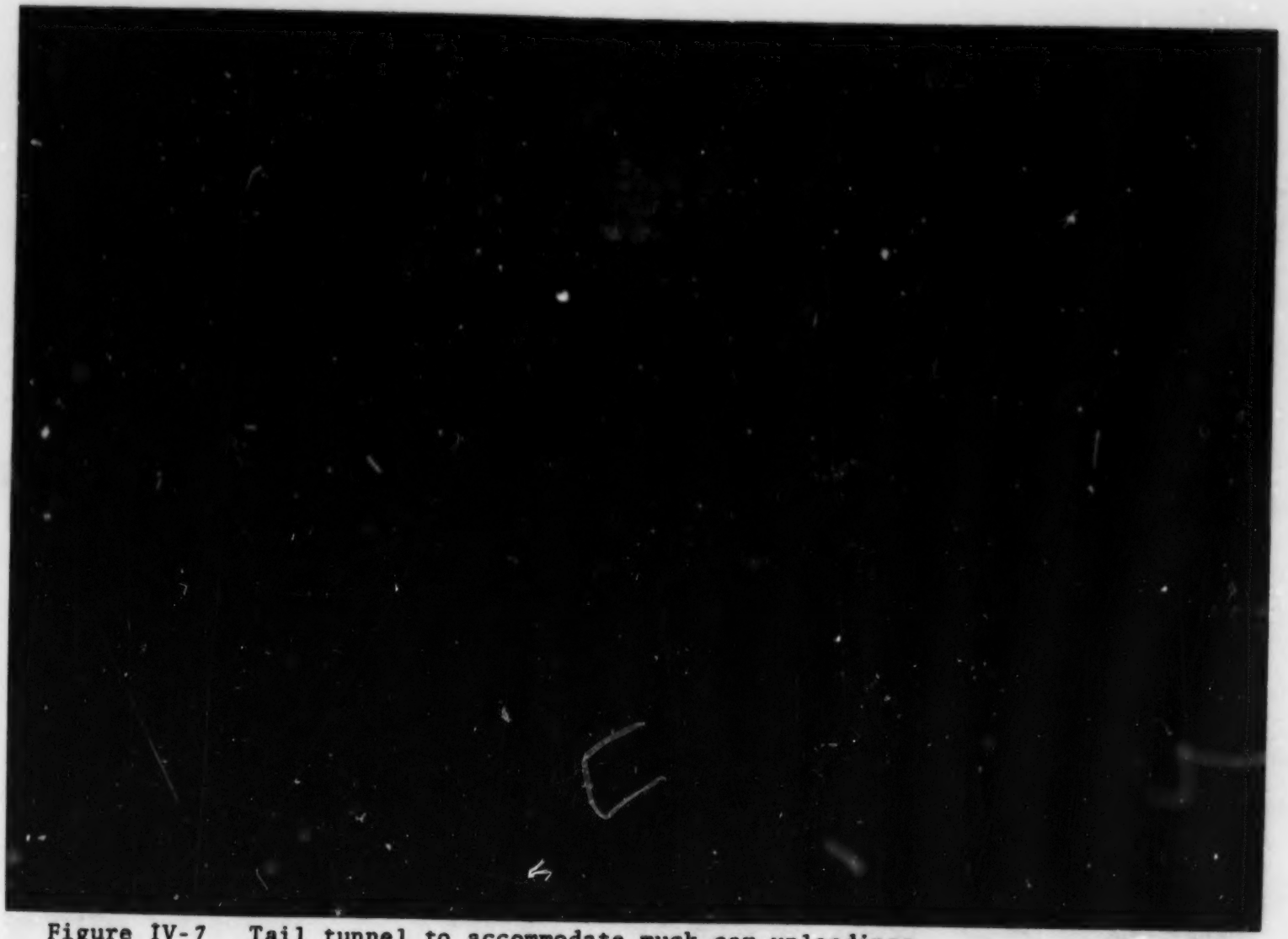


Figure IV-7 Tail tunnel to accommodate muck car unloadings.

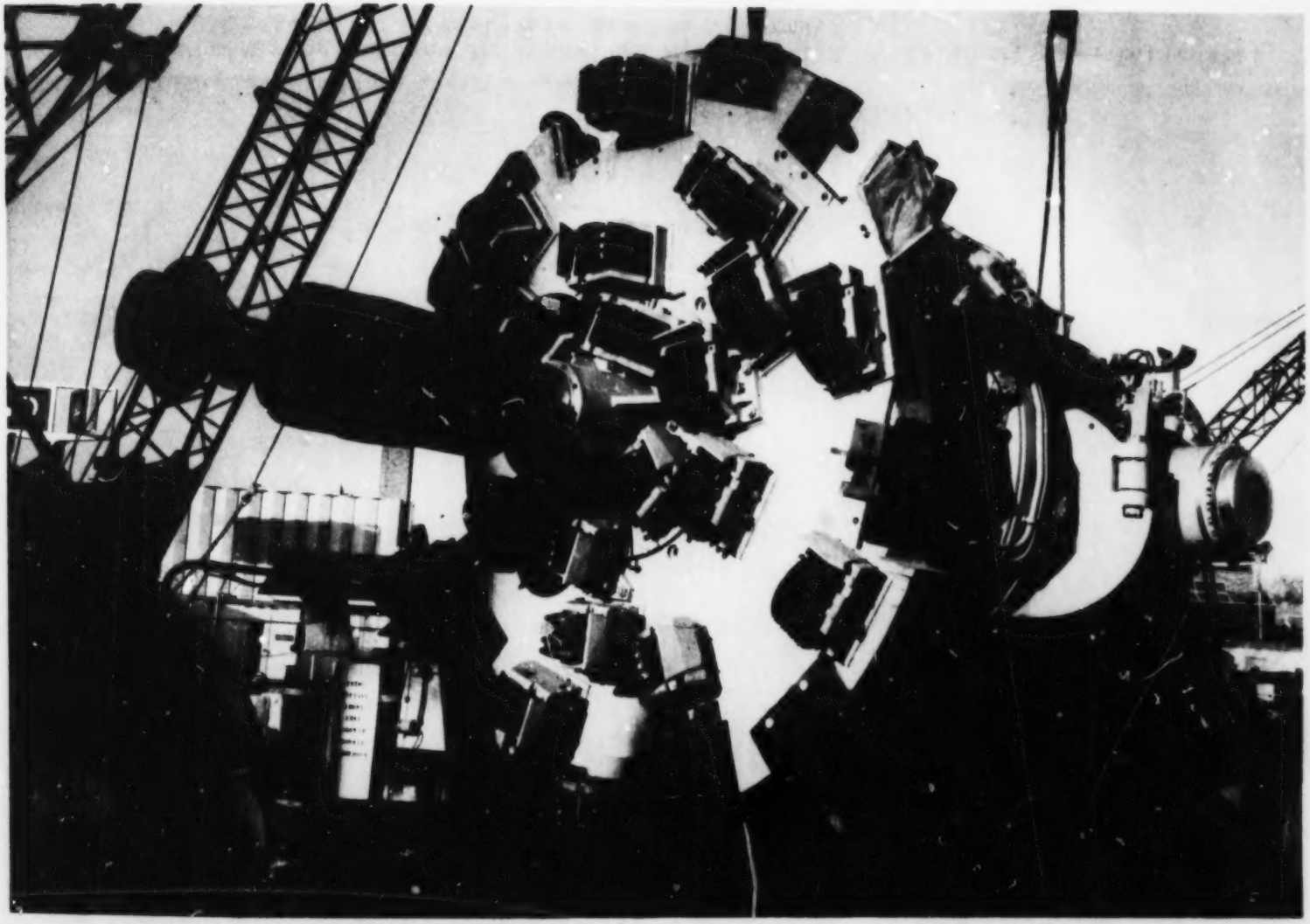


Figure IV-8 Mining machine shown at main shaft location prior to being placed into the tunnel.

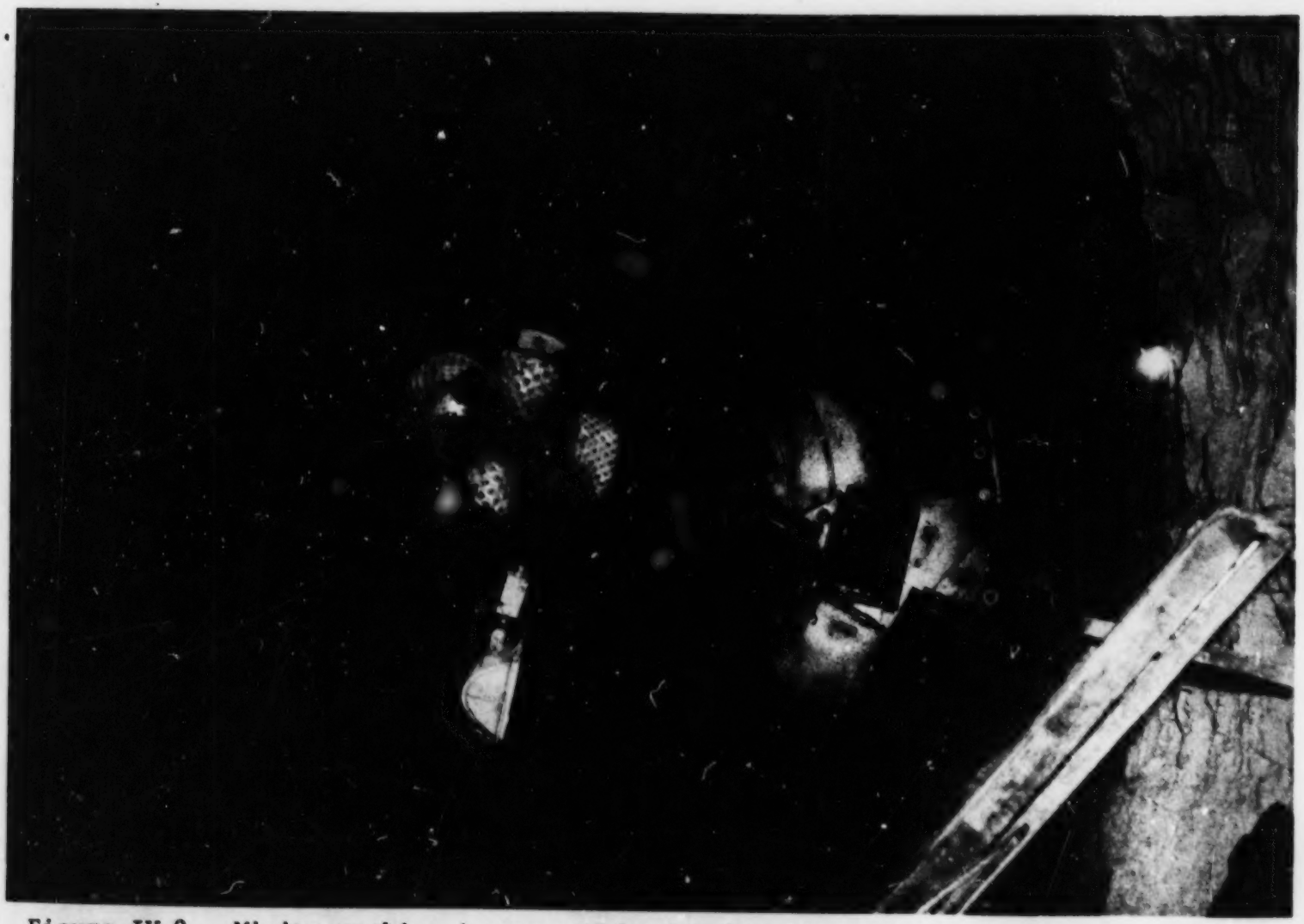


Figure IV-9 Mining machine in tunnel showing the 13'-8" (4.16 m) diameter cutter head with 29 disk-type carbide inserts.

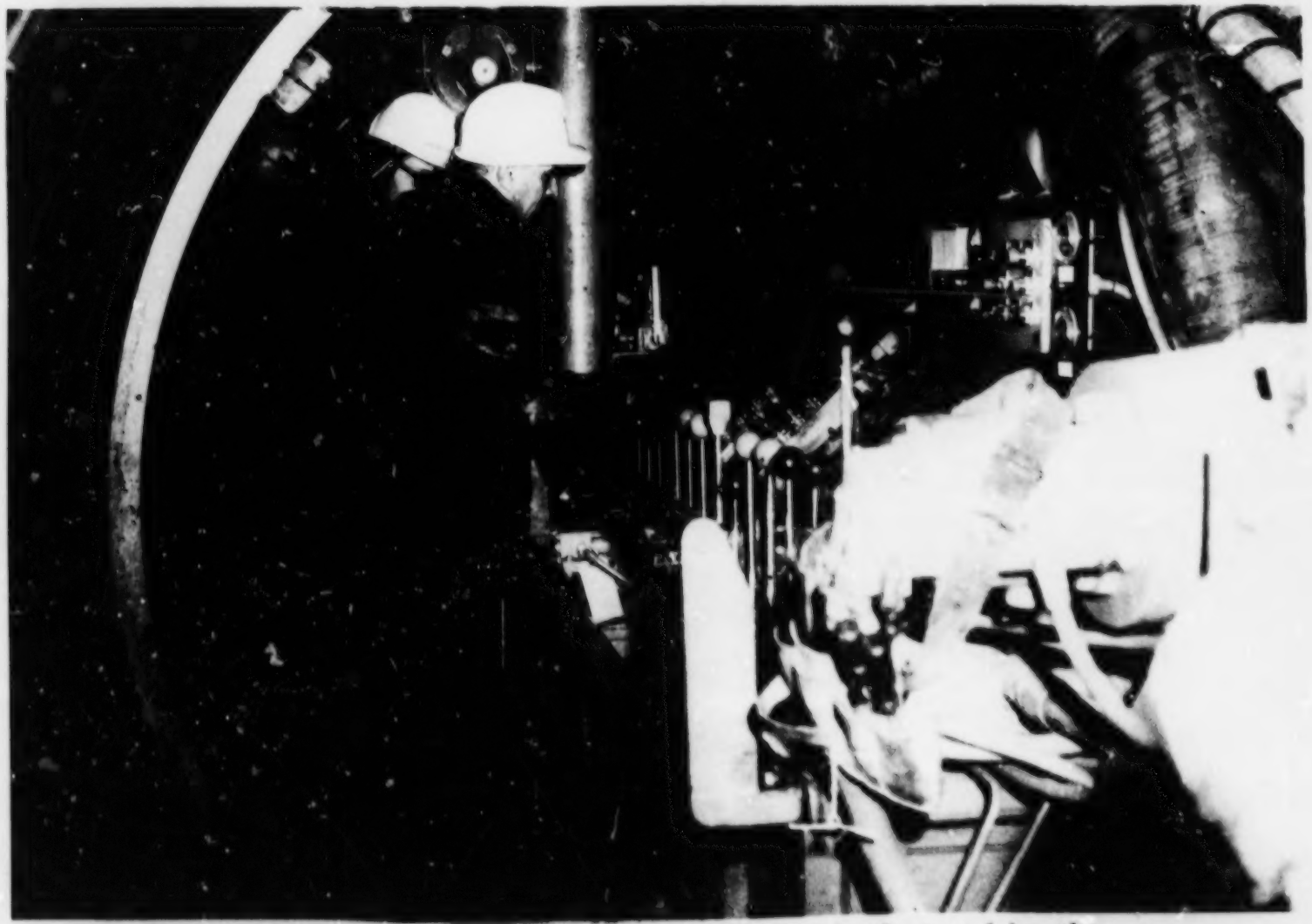


Figure IV-10 Control section of the mining machine manufactured by the Lawrence Mfg. Co. of Seattle, Wash.

Figure IV-11 Head frame and hoisting equipment at main shaft.

Some facts concerning major equipment items used by the Contractor, including the mining machine particulars, follows:

Mining Machine Data

Manufactured by:	Lawrence Mfg. Co. (Seattle, Wash.)
Thrust of Machine	1,300,000 lb. (589,680 kg) Maximum
Drive of Machine No. 1	5-125 hp. motors (126.75 hp - metric)
Drive of Machine No. 2	3-250 hp. motors (253.5 hp - metric)
Operation Voltage	480 Volts
Make of Bits	Lawrence Mfg. Co.
Number of Cutters	29 Disc-Type with carbide inserts
Dia. of Cutterhead:	
Machine No. 1	13'-8" dia. (4.16 m) in Lawrence Avenue
Machine No. 2	13'-9" dia. (4.19 m) in Harding and Lawrence
Length of Machine:	
Assembly	19'-11" (6.07 m)
Drawbar	15'-11" (4.85 m)
Power Train	23'-7" (7.19 m)
Auxiliary Power Train	25'-4" (7.72 m)
TOTAL LENGTH	84'-9" (25.83 m)
Tunnel Power Line	4,160 Volts
Conveyor System Manufacturer	Lawrence Mfg. Co. with a Goodyear Belt 24" (61 cm) wide by 84' (25.6 m) long
Muck Cars	6 Cubic Yards (4.59 m^3)
Length of Train	9 Cars
Track Gauge	36-inch (91.4 cm)
Locomotives	10 Ton (9072 kg) Plymouth Diesel, 86 hp (87.2 hp-metric)
Ventilation	28" (71 cm) Vent line 2-40 hp (40.56 hp-metric) Vent fans made by the Joy-Axivane Co., 14,000 CFM (396 m^3/min) each. One 15 hp (15.2 hp-metric fan at street level to prevent any line back pressures.
Line & Grade Control	By Laser Beam

Factors Adversely Affecting Progress:

1. The basic and major problem which had delayed completion of this contract, and the entire sewer system, had been the poor performance of the original mole. The machine when working properly could mine an average of about five lineal feet (1.5 m) of tunnel an hour. It was expected that the machine would be out of operation during periods that the cutters had to be replaced and normal maintenance performed. Many other malfunctions had to be corrected, some of them several times. The down-time reports include items such as bearing replacements, replacing cutter guard, repairing hydraulic leaks, repairing pilot cutter gear drive, disassembling hydraulic thrust system and repairing drive shaft housing, repairing transformer at Seattle plant, and many others.

The Contractor's "Critical Path Schedule" indicated an expected average mining rate of 282 lineal feet (86 m) per week with the mole, based on the claims of the manufacturer. After 49 weeks of actual performance, the machine had averaged about 132 ft. (40 m) per week and was completely worn out. The machine was dismantled and removed from the job and, while awaiting delivery of a new machine, the Contractor continued work by conventional drill and blast methods.

The second machine was placed in operation December 1, 1969 in Harding Avenue and later bored the Lawrence Avenue portion of 12-foot (3.7 m) tunnel. This machine bored an average of better than 6 lineal feet (1.8 m) per hour and, when full scale operation could be maintained, completed as much as 426 feet (130 m) in one week.

2. When the first mining machine performed so poorly, the progress of the tunnel work was definitely handicapped by the fact that the only point of ingress and egress to the work was through the main shaft. This is a calculated risk with deep tunnel work because of the high cost of excavating additional work shafts and installing hoisting equipment.

It should be pointed out that two similar rock tunnels were later contracted for by the Metropolitan Sanitary District based on the information gained by our pioneering of the Lawrence Ave. project. Each tunnel was bored by machine from a single shaft and completed in rapid fashion. Each machine used was by a different manufacturer than the ones tried on this project.

3. When the Contractor enlarged the 17-foot (5.2 m) tunnel to full size after drilling a 13'-8" (4.2 m) hole with the mole, he did not trim his blasted section to suit the steel form to be used in pouring the 8" (20.3 cm) concrete lining. Later while the mole was excavating westerly in Lawrence Avenue, the lining operations could also have been going on simultaneously, but the muck train movements to the shaft interfered with the trimming of these tight spots and as a result the concrete lining operations stopped for nine months.

4. Strikes by both the operating engineers and the truck drivers during the life of this contract also added to the Contractor's problems.

Contract Modifications:

1. The original machine was difficult to steer and thus maintaining line and grade was a problem. At the Contractor's request the finished invert grade was revised to suit the actual grade of tunnel as bored by the original mole for the first 6,128 feet (1,868 m). The costs to revise the design of the drop shaft structures because of this change were paid by the Contractor.

DEDUCTION = $12,250.00

2. Because of the excellent condition of the limestone rock in which the tunnel is located, see Figure IV-12, it had been decided that concrete lining of the machine-mined sections would not be required. Restoration work in some areas, consisting of rock bolts, wire mesh and guniting was performed. The Contractor submitted an acceptable proposal to do the work.

For Harding Av. Tunnel - ADDITION = $19,000.00

NOTE: By eliminating the concrete lining from these 12 ft. (3.7 m) tunnel sections, and performing only corrective work as stated, the total savings to the City was in excess of 800 thousand dollars. In addition, the elimination of the lining increased the storage capacity of the system by about 580,000 cubic feet (16,425 m^3).

3. Because of the Contractor's procedure in excavating the original 17-foot (5.2 m) tunnel first by machine bore and then enlargement by blasting, a substitute finished section was designed. To achieve equivalent area, an egg-shaped section resulted, with a 7'-6" (2.3 m) crown radius and a 6'-0" (1.8 m) invert radius. The maximum inside dimensions are 15'-6½"(4.7 m)

Figure IV-I2 Machine bored section of the tunnel showing the excellent condition of the limestone.

in width, and 19'-5" (5.9 m) in height. See figures IV-13, IV-14 and IV-15. There was no change in cost to the City for this modification.

4. Five time extensions were negotiated and approved. They were for 482 days, 30 days, 120 days, 153 days and 150 days.

5. Extra to perform tunnel restoration work in the Lawrence Avenue portion of the machine-mined tunnel.

ADDITION = $87,000

6. Tunnel inlet to the main shaft. ADDITION = $17,653

Other Items:

1. Contract Documents:

The length of tunnel actually excavated is less than that called for in the proposal quantities because of the design and location of the drop shaft structures. This information was not known when this contract was prepared and actually resulted in reducing the final cost of the contract.

The radius of the tunnel curve at Milwaukee Avenue was increased from 180' (54.9 m) to 500' (152.4 m) to accommodate the Contractor and to suit the length of the mining machine.

2. State and Federal Requirements:

Because both Motor Fuel Tax Funds and Federal Grant money were involved, the contract documents contained the inserts and specifications required by the agencies concerned.

3. Traffic and Safety:

The only construction shaft was located on MSDC property and therefore maintenance of vehicular traffic was not involved.

Safety regulations were documented in the specifications and were adhered to by the Contractor.

4. Supervision of Construction:

Supervision was more than adequate and the complaints regarding noise and vibration, which were to be expected where blasting was performed, were handled with skill and understanding.

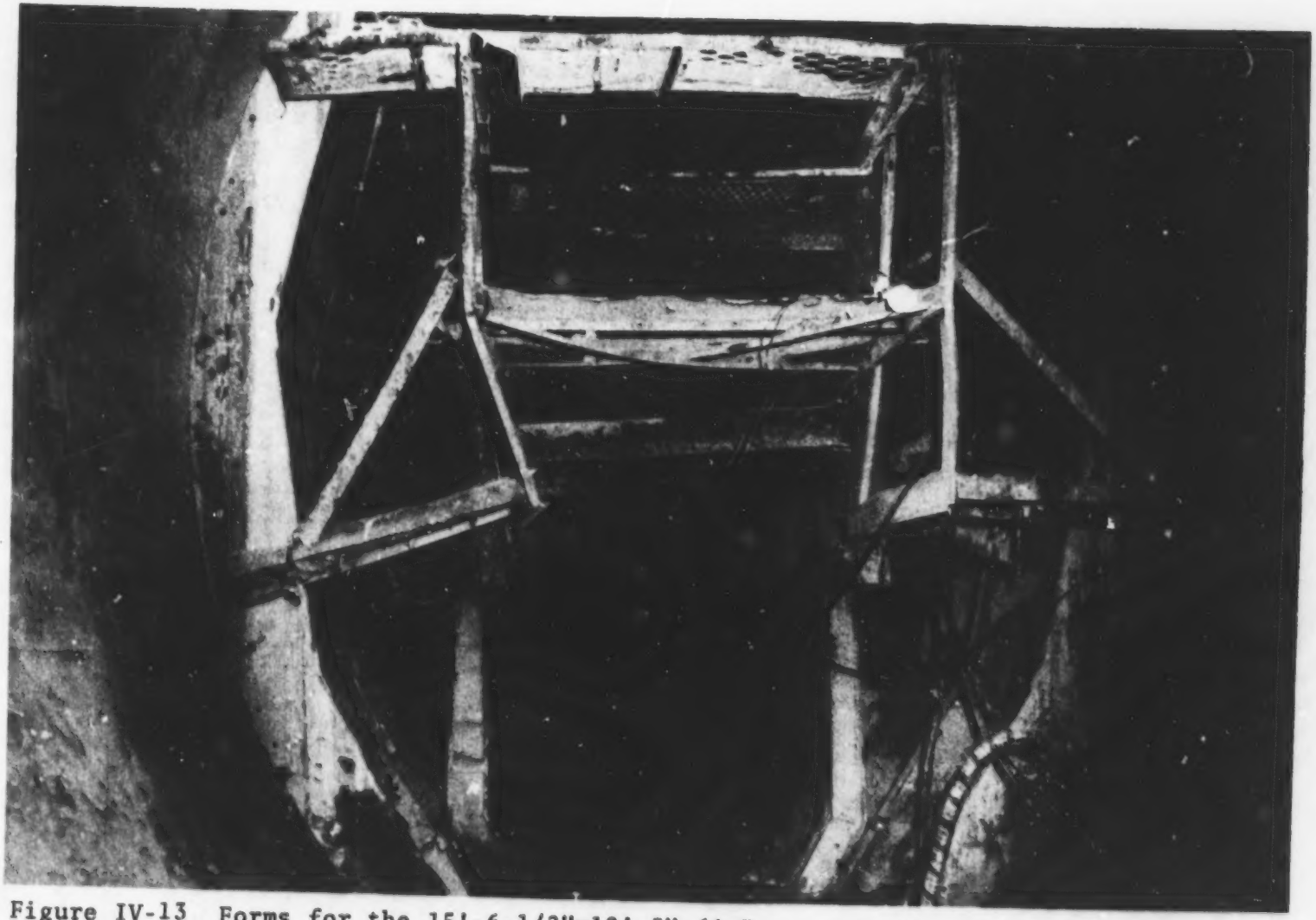


Figure IV-13 Forms for the 15'-6-1/2"x19'-5" (4.7 m x 5.9 m) concrete lining in section of tunnel in Lawrence Avenue enlarged from the 13'-8" (4.16 m) diameter machine bore size.

Figure IV-14 Concrete invert finishing of the 15'-6-1/2"x19'-5" (4.7 m x 5.9 m) concrete lined tunnel section.

Figure IV-15 Finished 15'-6-1/2"x19'-5" (4.7 m x 5.9m) lined section prior to forming transition to main shaft and pump sump.

Recommendations:

1. Wherever possible, rock tunnel-type sewer systems should be designed and constructed. Specifications should require the use of a mole within all practical size ranges.

2. The drop shaft structures should be included in the contract with the rock tunnel construction. This would give additional shafts for ingress and egress, and thus increased safety provisions, but also would provide the Contractor with a greater number of locations where muck could be removed.

3. The Contractor should be required to keep the floor of the tunnel cleaned of muck and debris. Also a better drainage system in the tunnel should be required. In this tunnel, walking any great distance was extremely difficult because of poor housekeeping.

Monitoring Wells

Contractor: Wehling Well Works, Inc.
Bid Price: $45,805.00
Financing: Sewer Bond Funds
Location: Just west of the southwest corner of Harding and Wilson Avenues.

Description & Purpose:

Three wells on 20-foot (6.1 m) centers were drilled to different depths with 12 3/4" (32.4 cm) diameter casings in earth and 10" (25.4 cm) bores in rock. These wells were installed so that the necessary data could determine if the Lawrence Ave. Underflow System has any objectionable effect on the Silurian aquifer and on the Wilson Avenue water tunnel which crosses Harding Avenue about 89 feet (27 m) above the sewer tunnel. These data consist of water level measurement recordings, and sampling taken from each well.

Contract Modifications:

There were no modifications or adjustments to final contract quantities as the work was successfully completed without the need to assess liquidated damages.

Comments:

A small job of this type created no traffic problems and was so specialized that it required customized plans and specifications.

Results To Date:

Since completion of the contract, results have been reviewed of water level measurements, and of the samples which have been taken on a monthly basis by personnel from the Bureau of Water, no adverse effect on water quality or quantity has been noted. The same frequency is to be maintained after the sewer system is in operation except that additional measurements and samples will be taken the day following any storm great enough to cause pressurization of the tunnel.

As a separate study, the wells were also tested by the Illinois State Water Survey in order to determine horizontal and vertical permeabilities of this aquifer.

Contract No. 2

High-Level Tunnels in Earth and Drop Shaft Structures

Problems Encountered With Contract No. 2

Bids for Contract No. 2 of this system were received on October 3, 1969 but were rejected as too high because the low bid of three received exceeded by 31.5% the estimate prepared by Harza Company. The contract in part called for the ten drop shaft structures to be constructed without disturbing the work being performed in the rock tunnel and making connections to the completed tunnel later.

The work originally proposed under Contract No. 2 was then split into two contracts by the City's Department of Public Works with construction of the drop shaft structures to be delayed until after the rock tunnel excavation was completed. This would be Contract 2-B. The balance of the proposed work was put into Contract 2-A and re-bid. The wisdom of this procedure was proven when the low bids for 2-A and 2-B combined totaled $389,305.00 less than the original No. 2 bid.

Contract No. 2-A

High-Level Tunnels in Earth

Contractor:	Reliance Underground Construction Company, Inc.
Bid Price:	$2,393,645.00
Financing:	52% of construction cost paid from City's share of Motor Fuel Tax Funds. Balance from Sewer Bond Funds.

Location:	In Menard Avenue from Lawrence Avenue to Berteau Avenue; in Melvina Avenue from Lawrence Avenue to Gunnison Street; in Moody Avenue from Gunnison Street to Strong Street to Mobile Avenue to Foster Avenue; and in Argyle Street from Mobile Avenue to Nagle Avenue.
Contract Description:	700 feet (213 m) of 5'-0" (1.5 m) diameter, 1,310 feet (399 m) of 6'-0" (1.8 m) diameter, 3,910 feet (1192 m) of 6'-6" (1.98 m) diameter, 1,540 feet (469 m) of 8'-6" (2.6m) diameter, and 960 feet (293 m) of 9'-6" (2.9m) diameter earth tunnel; 270 feet (82 m) of 12-inch (30.48 cm) diameter vitrified clay pipe; one monolithic concrete drop inlet structure; three monolithic concrete side weir inlet structures; three junctions; twelve drop pipe connections; manholes; catch basins; surface restoration; and all appurtenant and collateral work.
Estimated Cost of Revising City-Owned Utilities:	$53,947.41
Construction Starting Date:	March 16, 1970
Status:	All construction work completed June 1, 1972.

Construction Methods:

The tunnel sections were excavated with a Caldwell earthmining machine, equipped with hydraulic jacks to expand steel ribs and lagging against the earth sides as mining progressed. The contract, as bid on, specified five sizes of tunnel but permission was given to the Contractor to construct only two sizes, namely 9'-6" (2.9 m) and 6'-6" (2.0 m) finished diameter after reinforced concrete lining was poured. Where a larger-size sewer than specified was constructed, there was no additional cost to the City and the expense of revising the contract plans where required was paid by the Contractor.

Shafts for most of the connections were excavated with a vertical boring machine. With a 50-foot (15.2 m) high rig and an adjustable cutter, shafts varying from 8 ft (2.4 m) to 20 ft (6.1 m) in diameter were drilled.

The concrete tunnel lining was placed by pumping concrete into the tunnel and around a collapsible, portable steel form 70 feet (21.3 m) in length.

Temporary bulkheads were placed in all structures connecting to existing sewers to prevent water and sewage from entering the finished work from that source. Provisions were made under Contract No. 3 to remove these bulkheads when the system was ready to be put into operation.

Contract Modifications:

1. Revisions were required to some of the contract plans because the Contractor constructed larger tunnel sections than proposed. This was done at his expense. DEDUCTION = $2,500.00

2. Four time extensions were negotiated which totaled 328 calendar days. The last extension of 171 days was required because the remaining surface restoration awaited suitable weather.

3. Surface restoration item. ADDITION = $11,525.00

4. Adjustment to Final Contract Quantities. DEDUCTION =$23,043.24

General:

In the 25 years that the Auxiliary Outlet Sewer Program has been in existence, the City of Chicago's Department of Public Works has gained vast experience in the design, and supervision of construction, of sewers of this type.

Traffic requirements were worked out in advance with the Bureau of Street Traffic, coordination was maintained with public and private utilities, State Highway requirements (for Motor Fuel Tax fund approval) were met, City codes and ordinances were followed, public protection and safety were stressed, and in the case of this contract, 65 bid items were included in the proposal. It should not be surprising, therefore, that there were no inadequacies to report in any of the areas aforementioned.

Recommendations that have been received through the years were incorporated in the Plans and Specifications. The biggest factor in earth tunneling was to prevent movement of the surrounding earth and thus keep settlement to a minimum so that adjacent facilities were not damaged. Strict requirements to prevent settlement were included in our Specifications and enforced by the Department of Public Works' engineers who supervised the construction.

Contract No. 2-B

Ten Drop Shafts

Contractor: Rock Road Construction Company

Bid Price: $3,415,688.00

Financing: 52% of construction cost was paid from City's share of MFT Funds. Balance from Sewer Bond Funds.

Location: Ten Drop Shaft Structures located at:

1. Harding Avenue & Berteau Avenue
2. Harding Avenue & Montrose Avenue
3. Lawrence Avenue & Harding Avenue
4. Lawrence Avenue & Drake Avenue
5. Lawrence Avenue & Kildare Avenue
6. Lawrence Avenue & Kilbourn Avenue
7. Lawrence Avenue & Laramie Avenue
8. Lawrence Avenue & Long Avenue
9. Lawrence Avenue & Menard Avenue
10. Lawrence Avenue & Melvina Avenue

Contract Description: In addition to the above ten structures; three drop inlets; six side weir inlets; drain connections and all other appurtenant and collateral work.

Estimated Cost Of Revising City-Owned Utilities: $93,032.86

Construction Starting Date: February 28, 1972

Status: All construction work completed October 13, 1974.

Design:

During the design of these drop shaft structures, the services of the University of Minnesota, St. Anthony Falls Hydraulic Laboratory, were obtained. Studies were made with models to determine; the sizes of the shafts in relation to the quantities of flows entering from the high level sewers, air entrainment, the removal of the entrained air in the air collector in the boot of the structure and the dividing wall and deflectors as well as water surge conditions.

Model Studies:

The Lawrence Avenue Sewer System consists of a large deep tunnel for temporary storage of the surface runoff fed to it by a series of drop shafts placed at intervals along the axis of the tunnel. Each drop shaft was designed to handle a variable discharge, the peak value of which was different for each drop shaft. As the volume of runoff increases, the tailwater elevation will change from zero to a maximum governed by overflow facilities. The objective of the research was to investigate the nature of the flow in the drop shafts and to examine various alternative designs suggested by the results of the studies.

The essential purpose of the drop shaft is to transport water from one elevation and energy content to a lower elevation and lower energy content. Its function, then, is to dissipate the energy of the incoming flow in the course of its passage down the drop shaft to its new elevation and new flow pattern. If the drop shaft runs full, the energy change may be accomplished by friction along the wall of the drop shaft so that its energy at the bottom of the shaft is equal to that of the outflowing water. When the drop shaft is partially full, the change in energy is accomplished by impact of the falling water on the bottom of the shaft. For variable discharges, this change of energy is accomplished by a combination of boundary friction and impact.

In a system involving drop shafts of the height required by the Lawrence Avenue Sewer System, dissipation of energy by boundary friction alone required that the diameter be relatively small and that the flow velocities be quite high. It also requires that the drop shaft run full for all discharges that must be handled. For larger diameters and lesser velocities, the full flow condition can be attained in several ways. It is possible to maintain full flow to drop shafts for all discharges by using a valve at the bottom of the shaft. Full flow for a range of discharges could also be attained by introduction of air in varying amounts into the flow so that the water bulk will be increased sufficiently to fill the drop shaft. From the hydraulic point of view, use of a valve at the foot of the drop shaft is rather attractive, but it would have the disadvantage of being located far underground in the outlet tunnel and would require special instrumentation so that the valve opening could be governed by the inflow discharge. In addition, the valve would be subject to possible damage by sediment and other debris transported through the system. In the second alternative, that

is, the introduction of air into the flow, all obstructions to the flow and the necessity of moving parts would be eliminated, but the problem involving the development of a homogeneous mixture of air and water for all discharges in the drop shaft will probably be more difficult. Also, the design will have to provide for entrainment of proper quantities of air during the fall, its separation from the water and collection at the bottom, and its removal before being carried into the tunnel.

Because of the advantages that appear to be inherent in the air entraining type of drop shaft and because of experiences gained in previous studies of such drop shafts, the investigations for the Lawrence Avenue Sewer System were directed towards further development of such structures. Figures IV-16 through IV-26 show the results of experiments on several alternative systems which involve the entrainment of air in the drop shaft and the removal of this air from the flow at the bottom.

The development of the Type E-15 drop shafts consisted of successive tests of modifications of the basic structure. By observing the functioning of each design, changes were introduced which appeared to offer improved functioning. By this means the final arrangement was reached. The Type E-15 drop shaft will effectively remove entrained air before it reaches the downstream tunnel for all discharges up to its capacity and for all tailwater elevations above the crown of the downstream tunnel.

The sloping crown of the air collector is very important in order to effectively remove entrained air. It was also demonstrated by these tests that the slope of the air collector's crown should not be reduced, but an increase in slope would be beneficial to its operation. These experiments indicate that a slotted divider wall is more effective than a solid divider wall. If a slotted divider wall is used, then deflectors are necessary to deflect the flow away from the slot to provide the pressure distribution that permits air to be drawn into the flow and distributed over the cross-section. Of the deflectors tested, it appears that the largest deflector was the most effective, both from the point of view of air distribution and safety from damage by foreign bodies that might be carried by the flow.

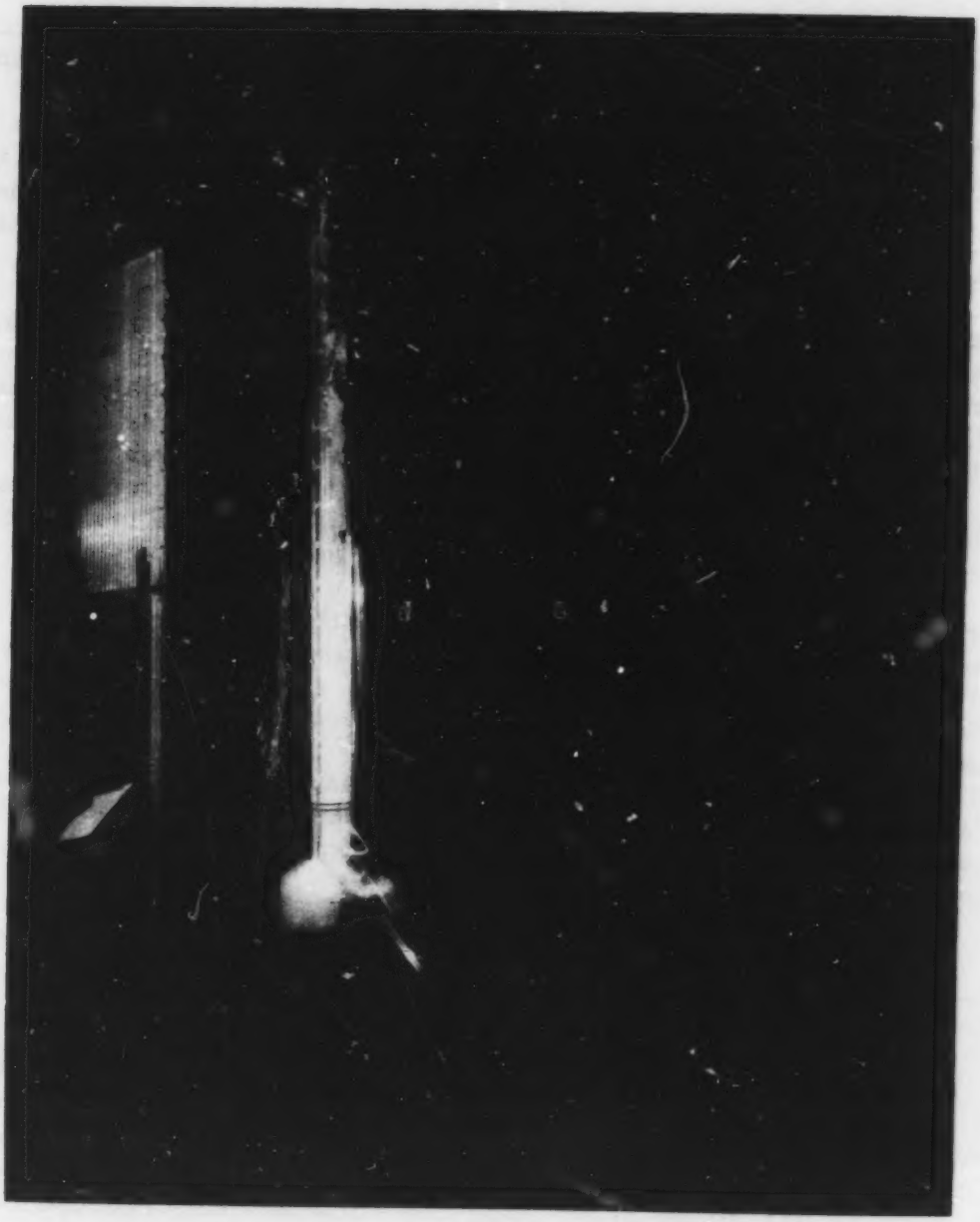


Figure IV-16 Overall View - Model

The drop shaft model was fabricated of a transparent plastic so that the flow patterns could be observed. The photograph shows a model slightly different from Type E-15 but is included here to demonstrate the relative size of the model and its characteristic features.

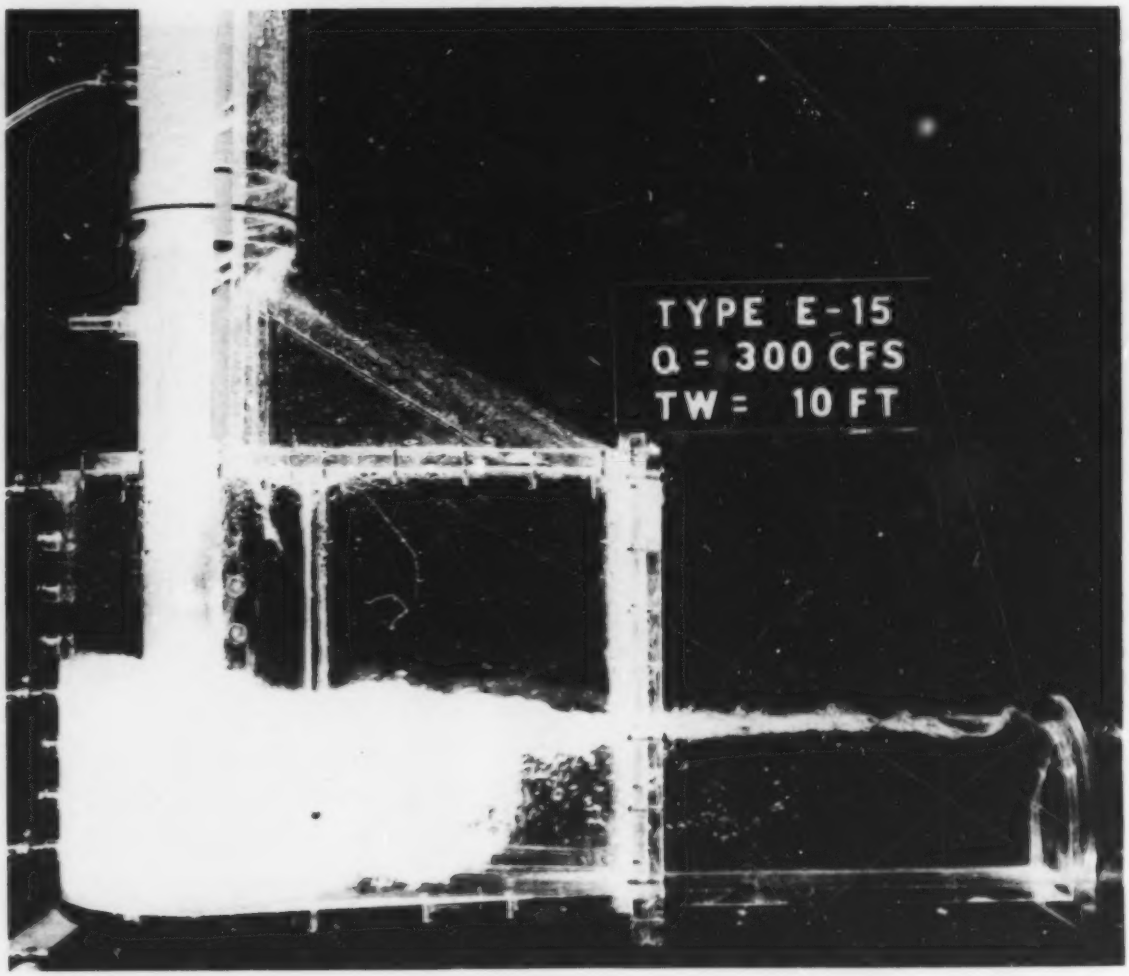


Figure IV-17 Exit Conduit, Q=300 cfs, TW=10 ft. ($8.5 m^3$/sec.), (3m)
This photo shows that for 300 cfs and a low tailwater of 10 ft. the air collector is effective in removing the air.

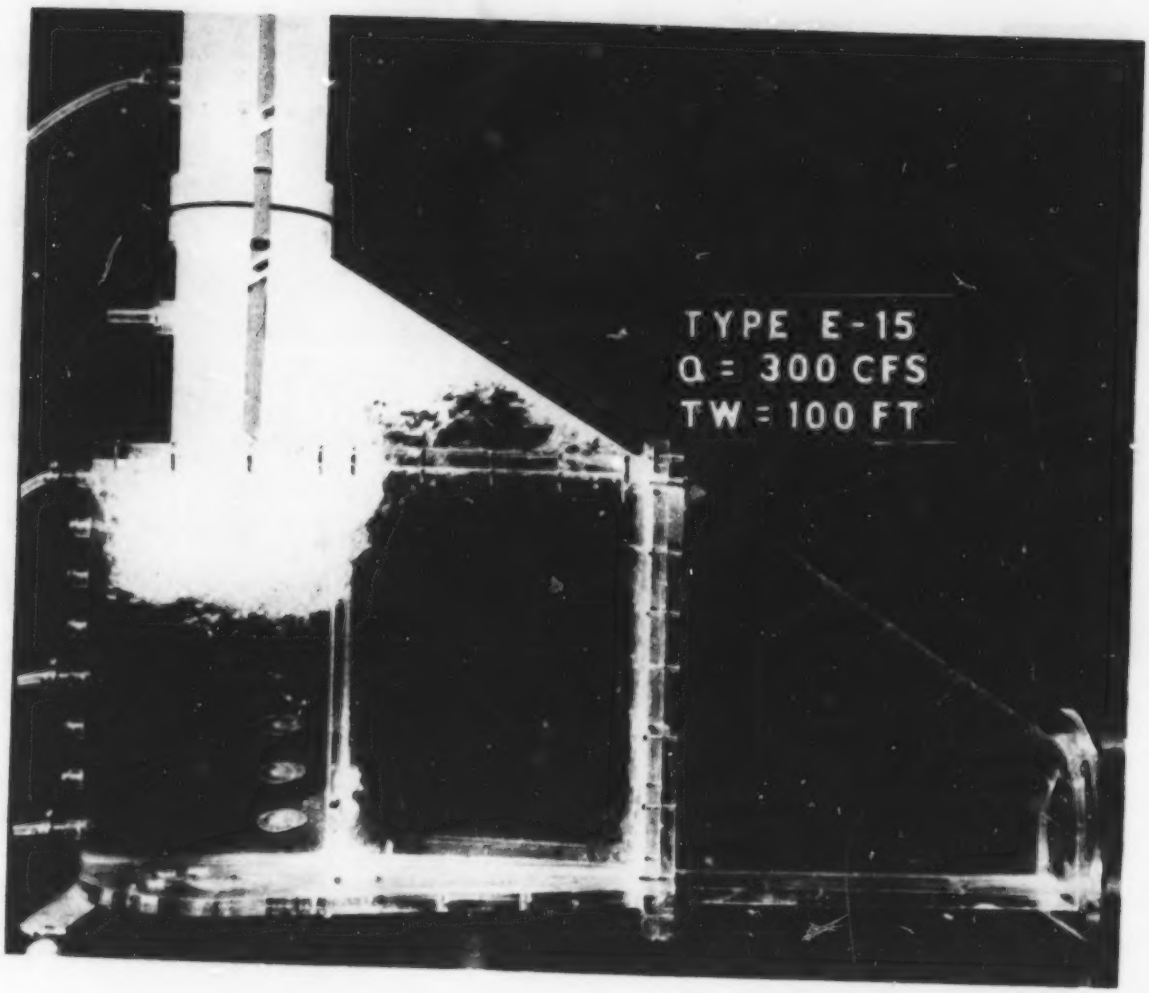


Figure IV-18 Exit Conduit, Q=300 cfs, TW=100 ft. ($8.5 m^3$/sec.), (30.5m)
For higher tailwaters such as shown in this photograph where the elevation is 100 ft. the Type E-15 can easily remove the air from the flow.

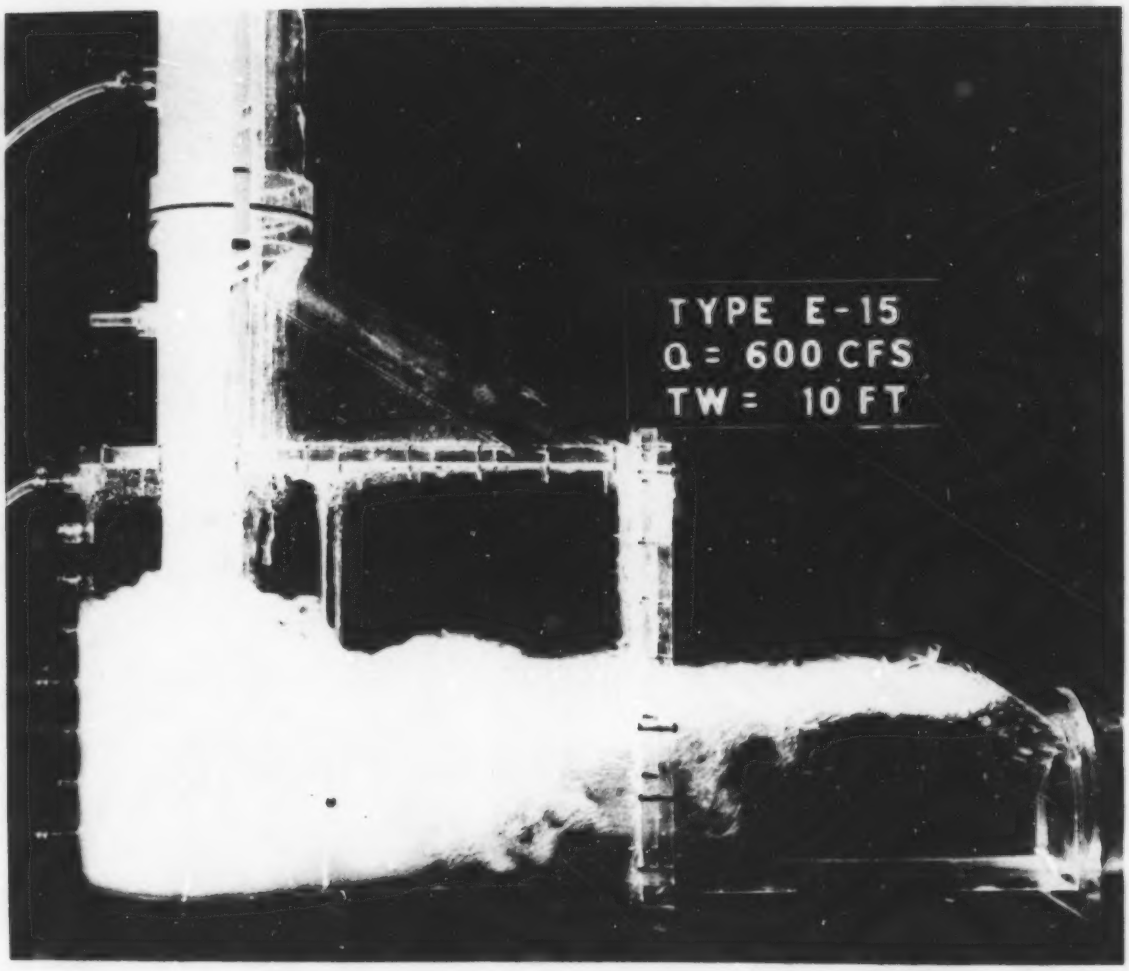


Figure IV-19 Exit Conduit, Q=600 cfs, TW=10 ft. ($17 m^3$/sec.), (3m)

For a discharge of 600 cfs and the tailwater maintained at 10 ft. the Type E-15 successfully removes the air from the flow.

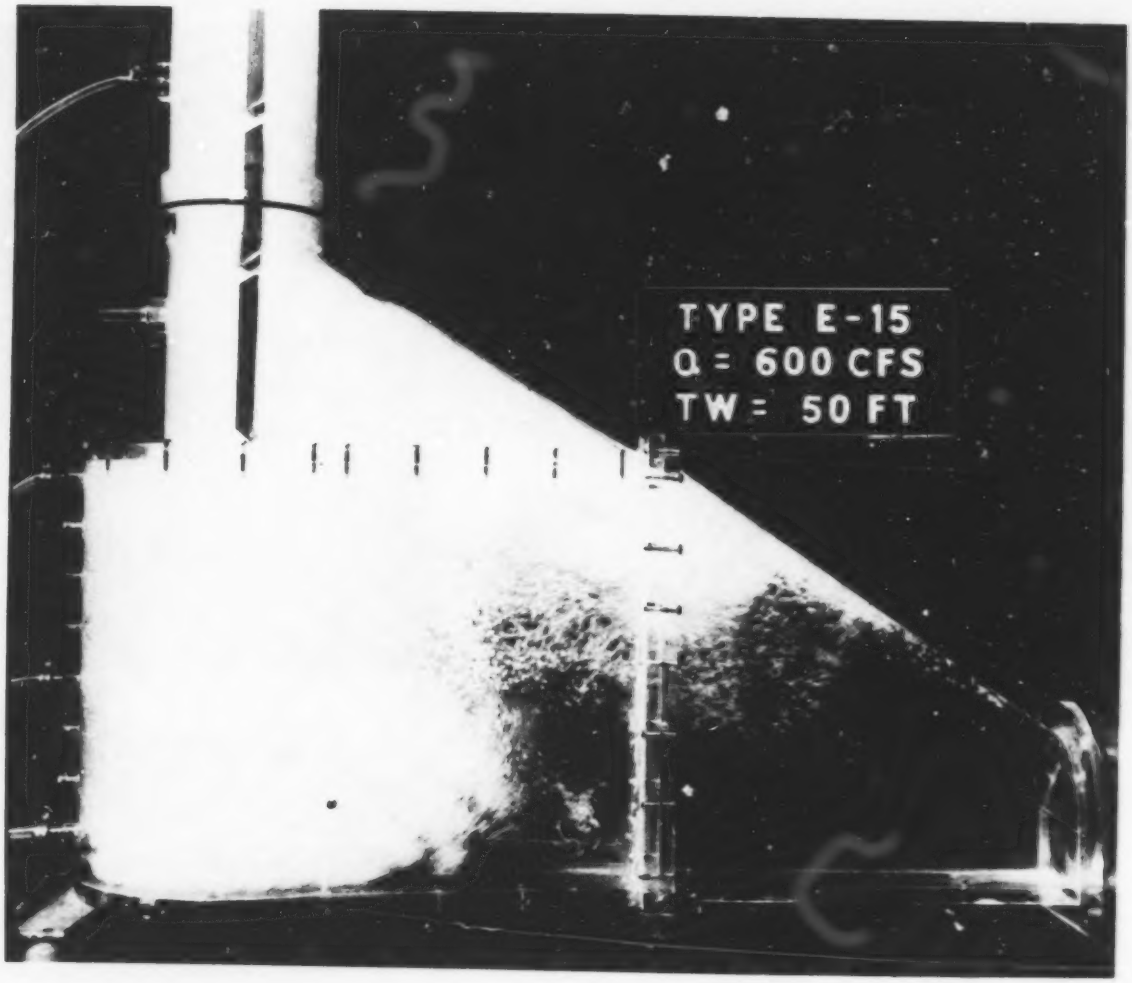


Figure IV-20 Exit Conduit, Q=600 cfs, TW=50 ft. ($17 m^3/sec.$), (15.2m)
When the tailwater has been raised to 50 ft. the entrained air quickly rises to the top of the air collector so that none can escape into the downstream tunnel.

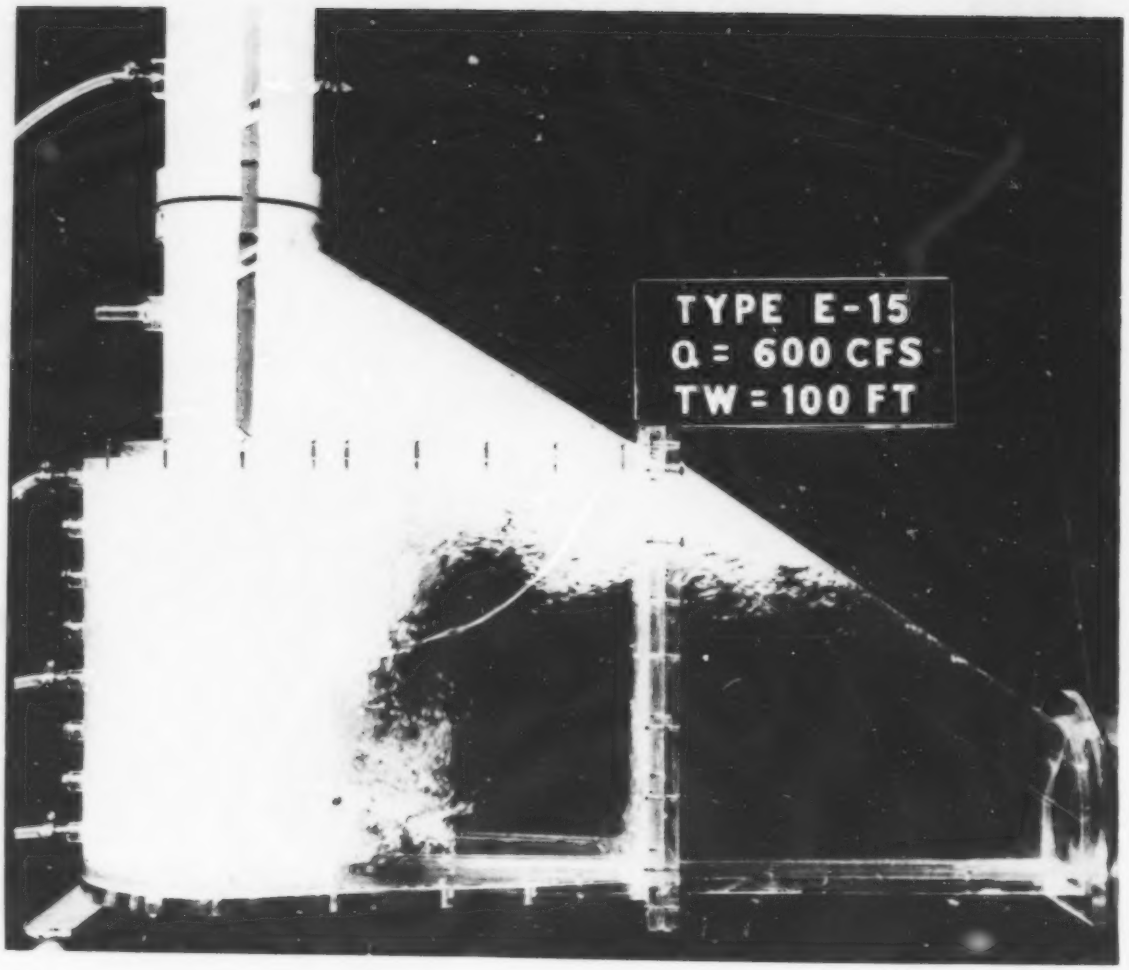


Figure IV-21 Exit Conduit, Q=600 cfs, TW=100 ft. ($17 m^3$/sec.), (30.5m)
For a tailwater of 100 ft. the air collector is still effective in removing air.

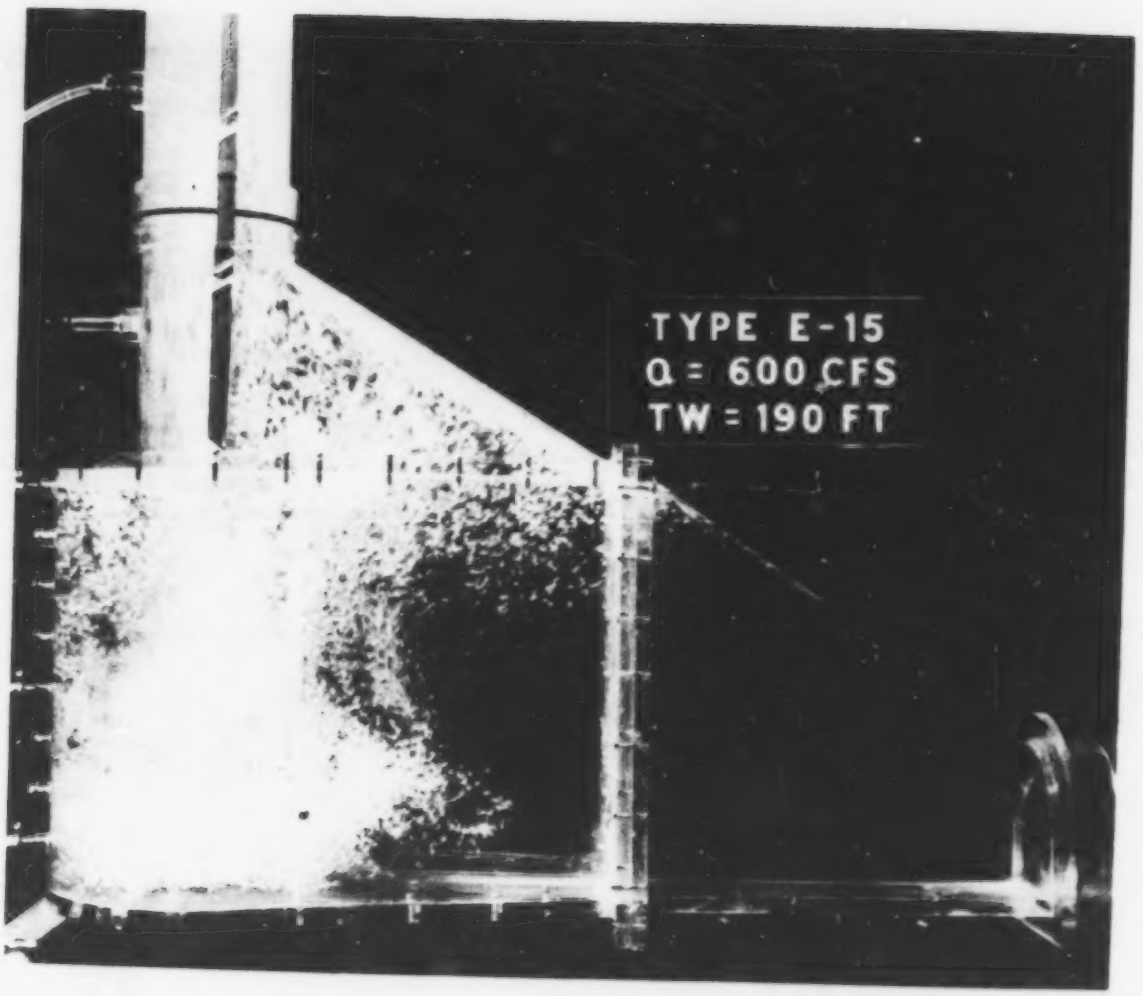


Figure IV-22 Exit Conduit, Q=600 cfs, TW=190 ft. ($17m^3$/sec.), (58m)

For a discharge of 600 cfs and a tailwater at 190 ft. the entrained air has been considerably reduced and the air collector can easily remove it from the flow so that none escapes into the downstream tunnel.

Figure IV-23 Vertical Shaft, Q=600 cfs, Effect of Air Slots ($17 m^3/sec.$)

This photograph shows a discharge of 600 cfs through the structure with a deflector over the air slots. The flow is homogeneous and no water escapes through the slots into the air vent.

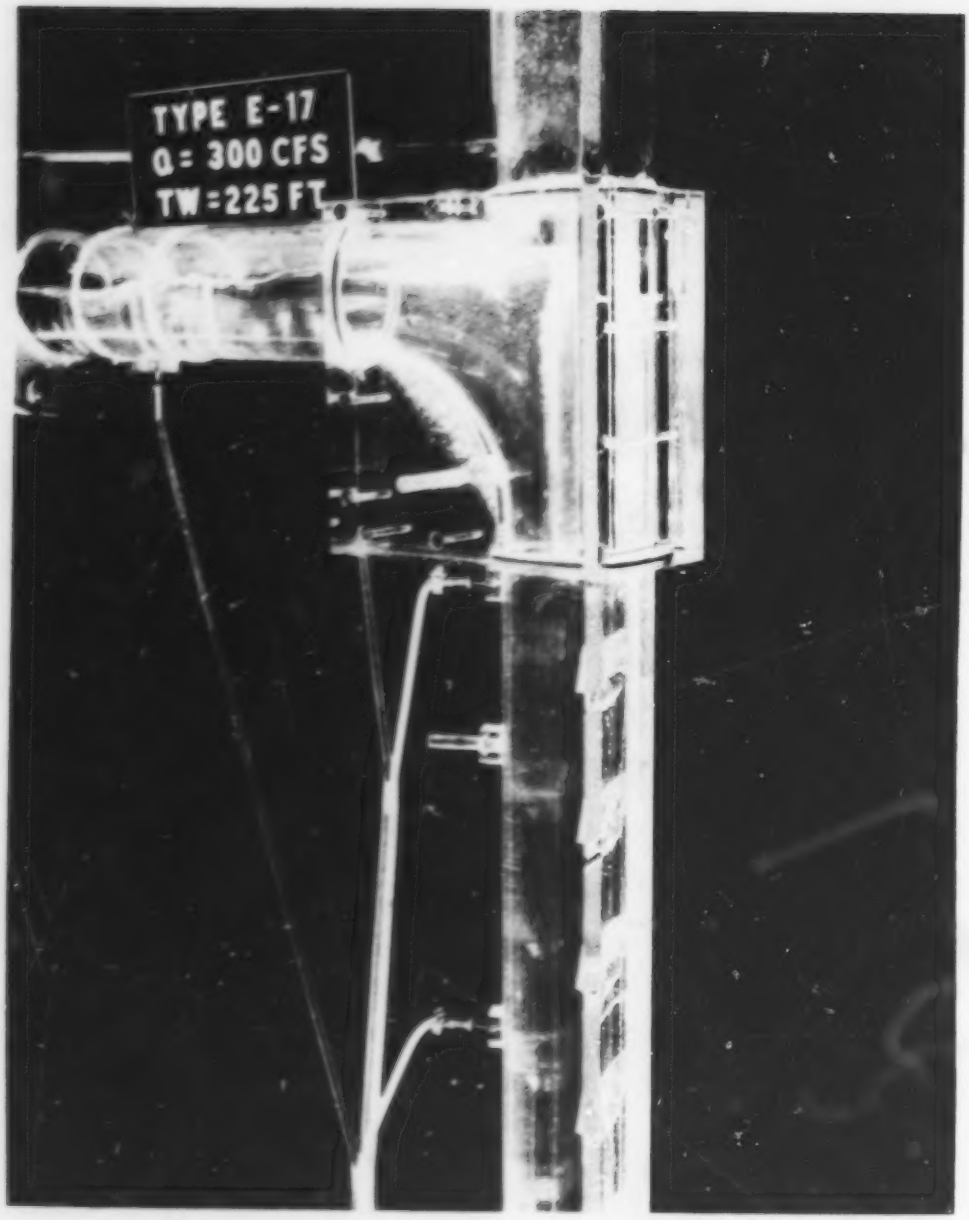


Figure IV-24 Entrance Conduit, Q=300 cfs, TW=225 ft. (8.5m^3/sec.), (68.6m)

When the discharge is 300 cfs with the tailwater at 225 ft. the incoming tunnel runs only partly full but there is no air entrainment. The drop shaft is full and the pressure difference between inlet and outlet is relatively small. (Shown for Type E-17, E-15 flow patterns are identical at this tailwater).

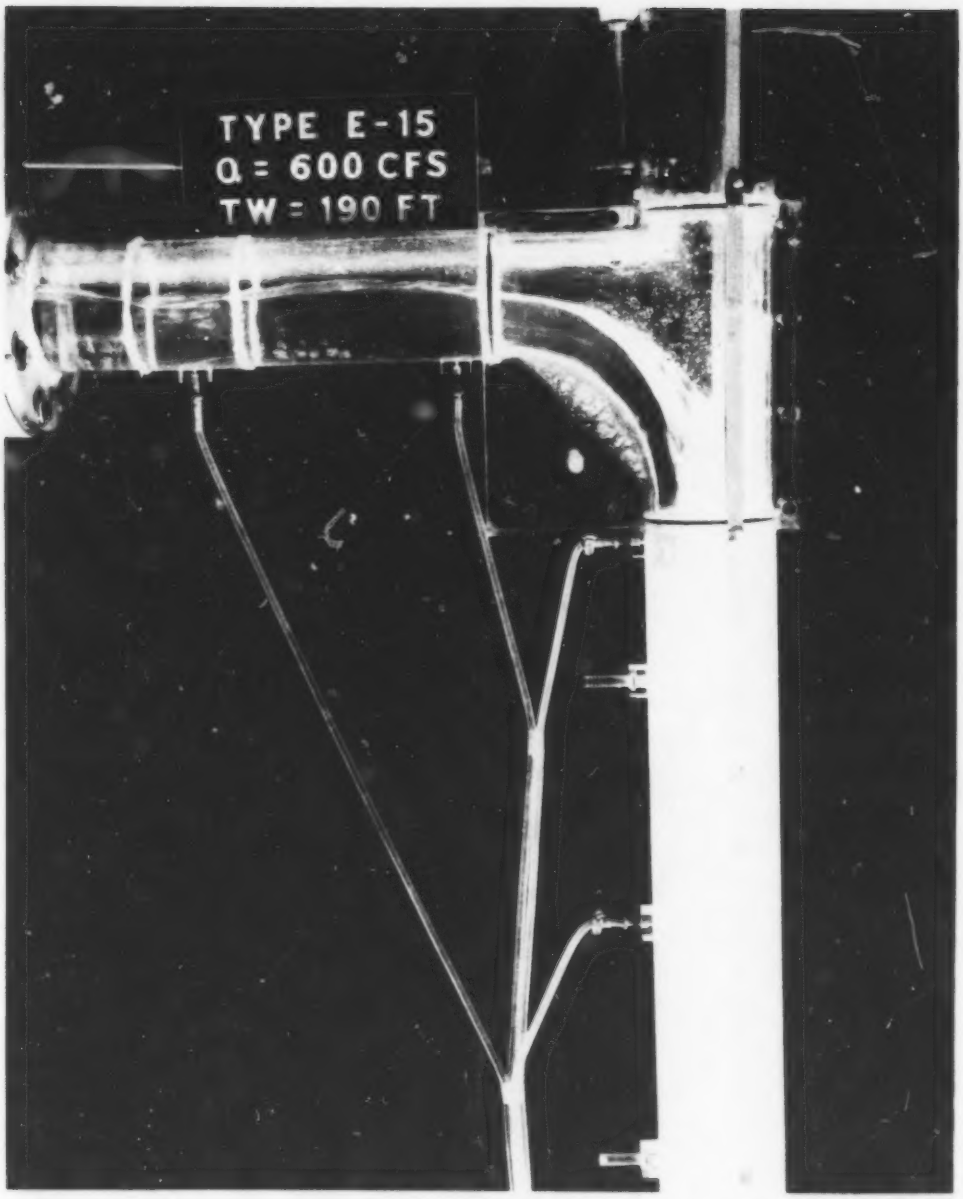


Figure IV-25 Entrance Conduit, Q=600 cfs, TW=190 ft. ($17m^3$/sec.), (58m)

When the tailwater is 190 ft. which is somewhat below the elevation of the incoming tunnel, the discharge of 600 cfs slows smoothly around the inlet and into the drop shaft proper. As it flows into the drop shaft, air is entrained and mixed with the water. The pressures in the incoming tunnel are atmospheric and the water surface represents the hydraulic gradeline.

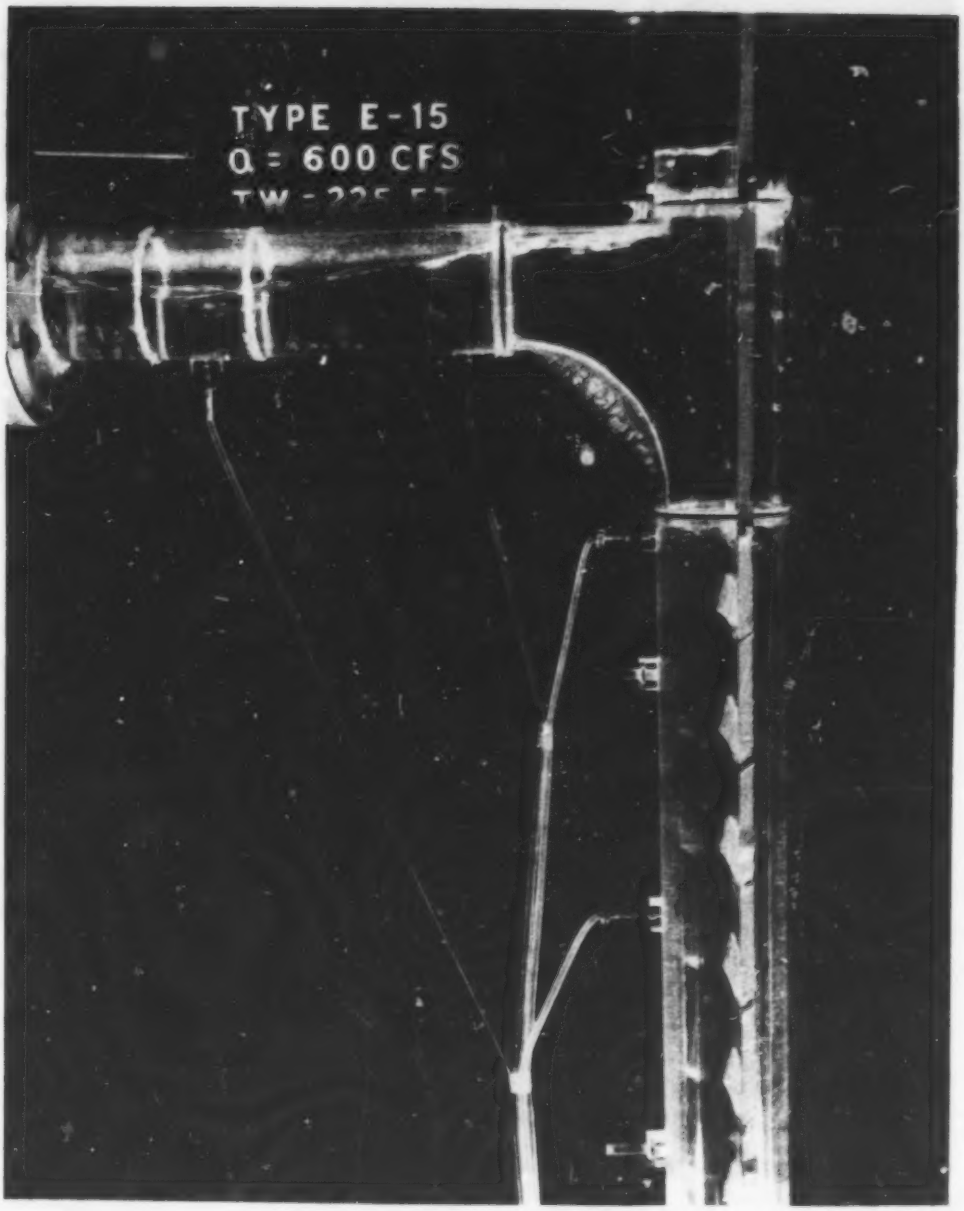


Figure IV-26 Entrance Conduit, Q=600 cfs, TW=225 ft. ($17 m^3$/sec.), (68.6m)
When the discharge is 600 cfs with the tailwater at 225 ft., the flow characteristics are essentially unchanged from when the flow is 300 cfs.

Construction Methods:

During the construction of this Contract, work also was proceeding on Contracts No. 1 and No. 3 by another Contractor which caused some conflict. The excavation of the drop shaft structures was accomplished by the raise bore method through the rock and by the down drill cutter machine through the overburden. See Figures IV-27, IV-28, IV-29 and IV-30. The form work for the concrete connecting section from the main tunnel to the drop shaft boot is shown in Figure IV-31.

Contract Modifications:

1. Relocation of existing sewers around drop shaft structures. ADDITION = $6,227.90
2. Restore existing 15-inch sewer in Laramie Avenue through no fault to Contractor. ADDITION = $7,935.50
3. Five time extensions were approved for a total of 407 days.
4. Additional manhole added. ADDITION = $295.00
5. Final Contract Quantity adjustment. DEDUCTION = $30,376.30

Contract No. 3

Pumping Station and Outfall

Contractor: Joint venture of James McHugh Construction Company. S.A. Healy Company, and Kenny Construction Company.

Bid Price: $1,977,000.00

Financing: 52% of construction cost was paid from City's share of Motor Fuel Tax Funds. Balance from Sewer Bond Funds, and from Federal Funds.

Location: Lawrence Avenue at North Branch of Chicago River.

Contract Description: Pumping facilities; outfall structure; yard area; main shaft concrete lining; a discharge line to the M.S.D.C. interceptor; the removal of existing temporary brick, concrete and wooden bulkheads; the construction of brick weirs; and the performing of all appurtenant and collateral work.

Construction Starting Date: April 17, 1972

Construction Status:

Figure IV-32 shows main shaft features installed following placing of the concrete lining prior to installation of the elevator.

Figure IV-33 shows one of the submersible pumps.

Figure IV-27 Down drill rig at the drop shaft at Lawrence Ave. and Menard Ave. for drilling through the overburden prior to rock drilling by the raise-bore method.

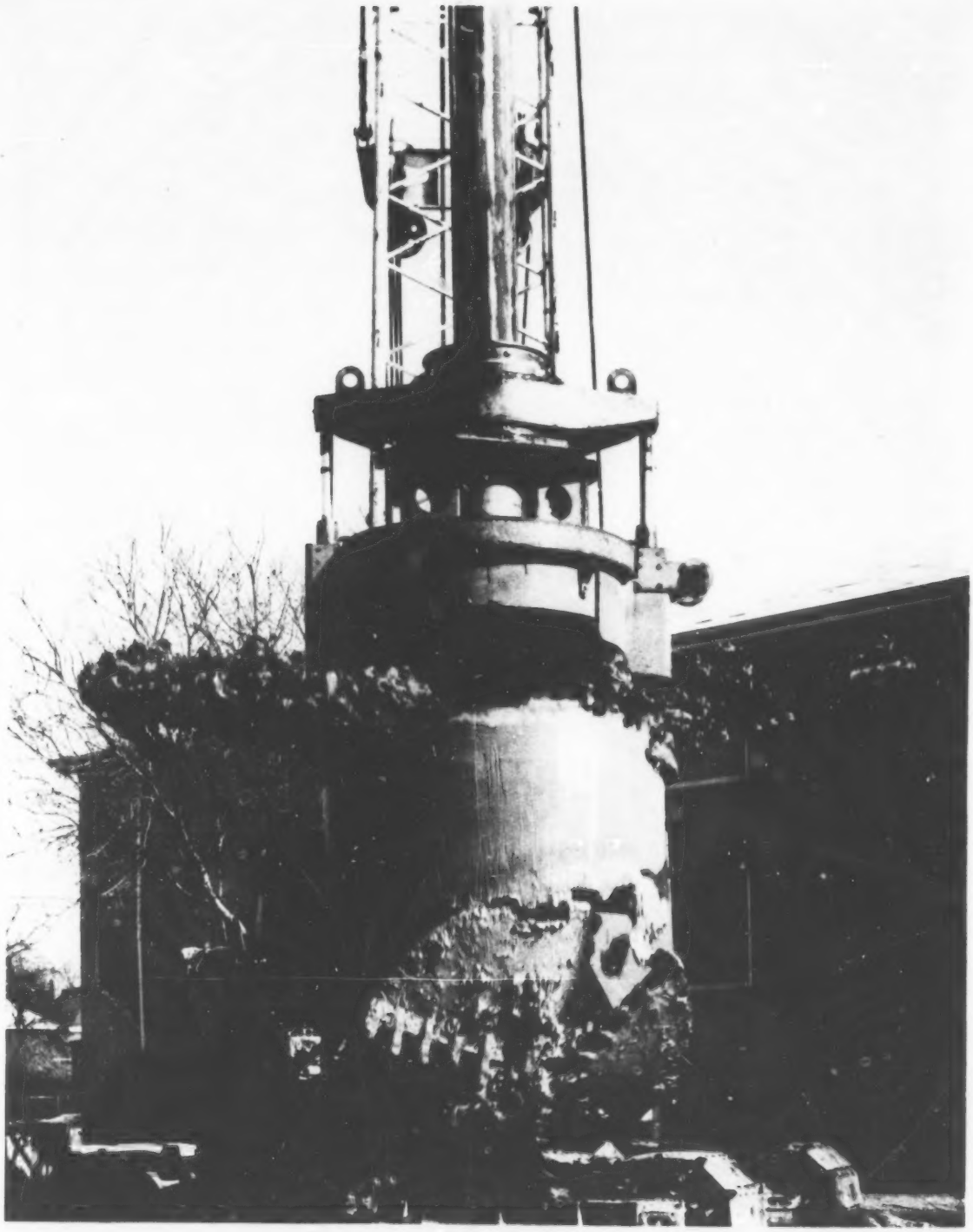


Figure IV-28 Close up view of the down drill cutter head for drop shaft excavation.

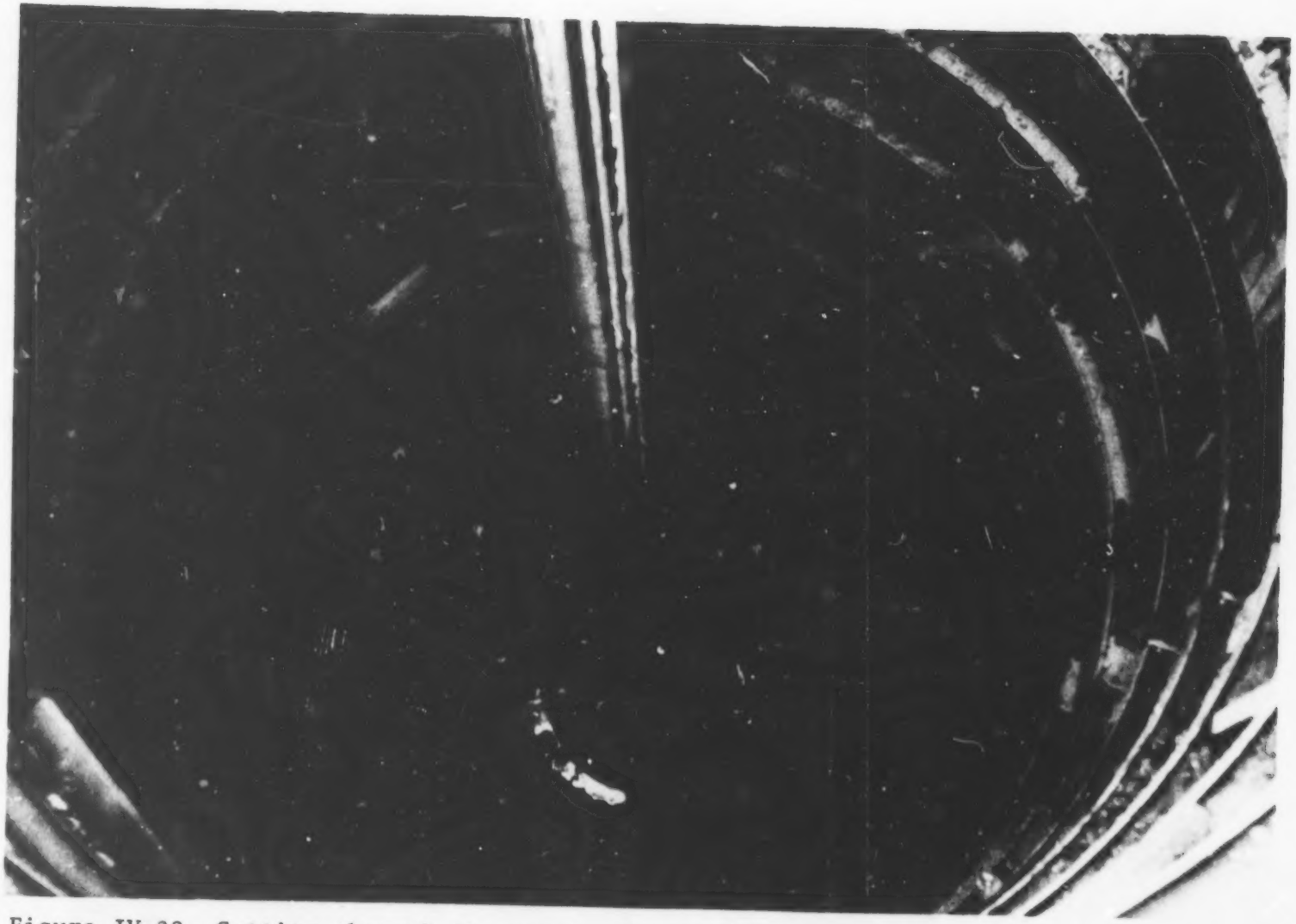


Figure IV-29 Cutting through the overburden at the Menard drop shaft showing steel rings and sheeting installed.

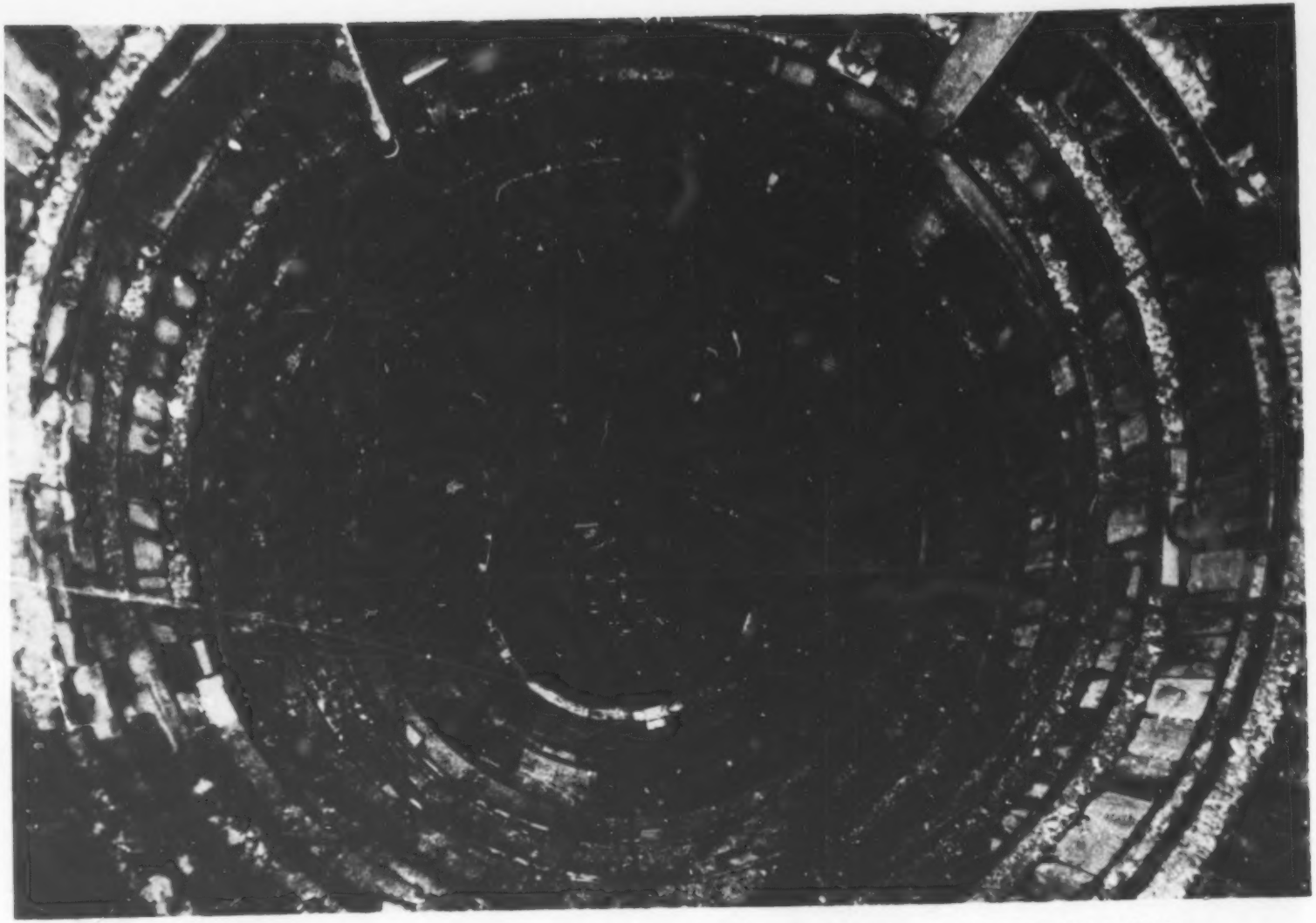


Figure IV-30 Down view of the Menard drop shaft showing rock excavation below sheeted overburden section.

Figure IV-31 Erecting form work for the concrete connecting section from main tunnel to the drop shaft boot.

Figure IV-32 View down main shaft showing concrete lining, trash rack grooves and the air vent pipe prior to elevation installation.

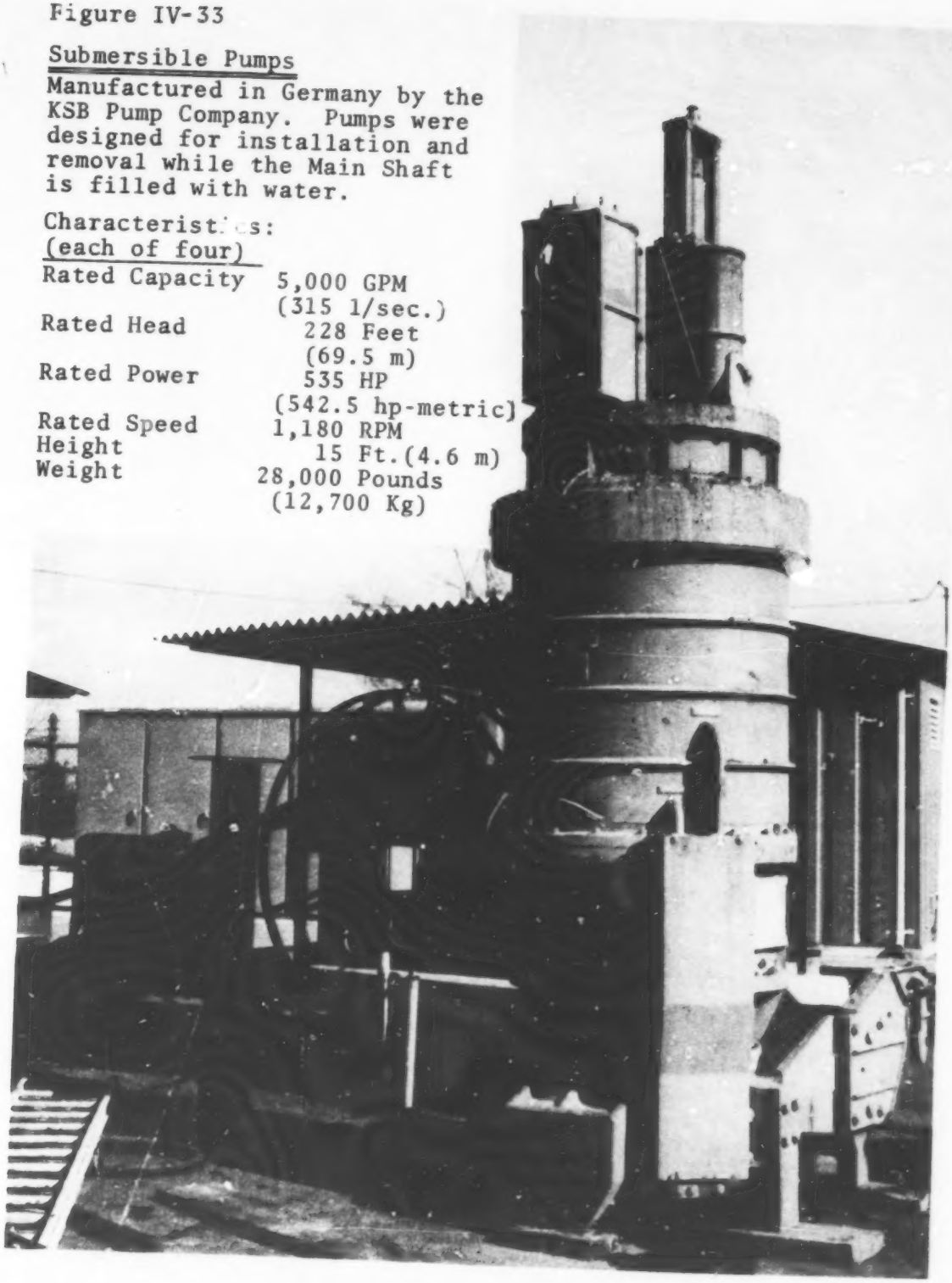
Figure IV-33

Submersible Pumps

Manufactured in Germany by the KSB Pump Company. Pumps were designed for installation and removal while the Main Shaft is filled with water.

Characteristics:
(each of four)

Rated Capacity	5,000 GPM (315 l/sec.)
Rated Head	228 Feet (69.5 m)
Rated Power	535 HP (542.5 hp-metric)
Rated Speed	1,180 RPM
Height	15 Ft.(4.6 m)
Weight	28,000 Pounds (12,700 Kg)



As of Feb. 1979, the contract work was 96.65% completed. Pump failures had occurred due to infiltration or intrusion of water into the upper chamber of the junction boxes which caused considerable delays. This was believed to have been caused by water absorption through the power cable jacket after long periods of submergence or through faulty junction boxes. Although the cables were installed per specifications, it became necessary to research new cables which now have testing laboratory approval.

The use of Okonite control cables now requires larger diameter reels and gear modifications in gear boxes to operate the reels. This problem is currently being resolved.

Contract Modifications:

1. Revision of electrical work in the control chamber. ADDITION = $1,702.00
2. Domestic water supply change. ADDITION = $3,680.24
3. Furnishing and placing four pump discharge diffusers. ADDITION = $5,161.29
4. Heating system for pump supply line. ADDITION = $189.62
5. Additional reinforcement steel for baffle walls. ADDITION = $311.08
6. Replacement of blown terminal boxes. ADDITION = $50,125.00
7. Starter-fuses (spare parts). ADDITION = $3,426.89
8. Miscellaneous protection devices. ADDITION = $1,108.68
9. Modification of 14-inch ball valves. ADDITION = $948.75
10. Grate modification to clear hoisting chains. ADDITION = $3,162.50
11. Disposal of debris for bulkhead removals. ADDITION = $5,325.34
12. Plywood covers at main shaft (freeze prevention). ADDITION = $2,173.50
13. Replacement of manhole covers for Outfall Structure (36-inch-double openings). ADDITION = $612.38
14. Crane charges for Pump removals. ADDITION = $4,606.70
15. Pumping Costs. ADDITION = $3,474.60
16. New Cables - Okonite, power & control. ADDITION = $73,729.00
17. Modifications for new cable reels. ADDITION = $20,013.00
18. Five time extensions have been approved as of April, 1978 for a total of 973 days.

Contract No. 4

Additional High-Level Sewers

Contractor:	Jay-Dee Contractors, Inc.
Bid Price:	$2,644,875.00
Financing:	Sewer Bond Funds
Location:	In Drake Avenue from Lawrence Avenue to Argyle Street; in Long Avenue from Lawrence Avenue to Montrose Avenue; in Melvina Avenue from Lawrence Avenue to Eastwood Avenue to Narragansett Avenue to Montrose Avenue; and in Strong Street from Moody Avenue to Austin Avenue to Higgins Avenue.
Contract Description:	3,930 feet (1198 m) of 6'-0" (1.8 m) diameter and 4,610 feet (1405 m) of 5'-0" (1.5 m) diameter earth tunnel; 1,245 feet (379 m) of 60-inch (152.4 cm) diameter reinforced concrete pipe; one monolithic concrete drop inlet structure; three monolithic concrete side weir inlet structures; eight drop pipe connections; manholes, catch basins, surface restoration; and all appurtenant and collateral work.
Construction Starting Date:	May 1, 1974
Status:	All construction work completed June 30, 1975.

Contract Modifications:

1. The Contractor proposed to construct the Drake Avenue branch by the jacking-tunneling machine method. This allowed the City the advantage of minimal street replacement and traffic disruption for a credit of surface restoration items. See Modification No. 3. ADDITION = $27,340.00
2. Spot welding of air vent gratings to frames. (Vandalism prevention). ADDITION = $143.00
3. Total adjustment to Contract. DEDUCTION = $47,852.81

LAWRENCE AVENUE TESTING DEMONSTRATION

The entire Lawrence Avenue System did not receive flow until the outfall and pumping station included in Contract No. 3 were completed and the pumps were installed.

In accordance with our agreement for Federal (USEPA) Demonstration Grant Funds an extensive testing program must be undertaken with samples taken of storm overflows from sewers of and influenced by the Lawrence Avenue System to demonstrate its

performance. Sampling and testing for the pre-operation condition has been completed.

The sampling and testing for the post-operation condition will be conducted when the Pumping Station is fully operational. This work will consist of testing for the following; Biochemical Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen, Settleable Solids, Suspended Solids, Fecal Coliform, Organic nitrogen, Ammonia nitrogen and Spectroanalysis for metals. The results of this sampling and testing program will be covered in the Phase II, Final Report.

RELATIONSHIP OF THE LAWRENCE UNDERFLOW SYSTEM TO THE TUNNEL AND RESERVOIR PLAN

The Metropolitan Sanitary District of Greater Chicago is now constructing segments of the Tunnel and Reservoir Plan (TARP). This system is comprised of a series of rock tunnels and reservoirs. The tunnels are approximately 250 feet (76 m) below the surface and are designed to capture combined sewer flows, which presently overflow to the river during times of storm, and convey them to storage reservoirs for containment until capacity is available at the treatment plants.

When the Mainstream Section of the TARP is in operation, the pumping station of the Lawrence Avenue System will be a branch of the entire waterway flood and pollution control system. The capacity of the Lawrence System to handle combined sewer overflows will then be increased. This is significant because the rock tunnels of the Lawrence System can then be used as an outlet for flows originating from areas beyond its currently designed drainage area of 3600 acres (1457 hectares). It is recommended that the maintenance and operation of the Lawrence Avenue System be undertaken by the Metropolitan Sanitary District of Greater Chicago who have personnel qualified to handle pumping stations of this type. In addition, the system will eventually be a direct connection to the District's Tunnel and Reservoir Plan.

SECTION V

TUNNEL AND RESERVOIR PLAN FOR THE CHICAGOLAND AREA

DESCRIPTION

The Tunnel and Reservoir Plan (TARP), currently under construction by the Metropolitan Sanitary District of Greater Chicago (MSDGC). has been selected from fifty-one considered proposals as the most cost-effective method which will prevent combined sewer overflows to the waterways, except for the recurrence of the three largest storms of record, and will eliminate backflow from the waterways to Lake Michigan. During spills from these events, the flows would be relatively clean since the highly-polluted, "First Flush," would be captured by TARP during the early stages of rainfall.

TARP is actually made up of 125 miles (201 km) of tunnels including their related collector systems, an aquifer protection system, two on-line reservoirs, three terminal (retention) reservoirs, and treatment facilities. See Figure V-1.

Based on currently available or anticipated funding, construction has been divided into four separate systems, viz; Mainstream, Calumet, Main(Lower) Des Plaines, and Northwest (Upper) Des Plaines. For the Mainstream and Calumet Systems, Stage 1 construction is primarily for pollution control and Stage 2 is primarily for flood control. Stage 2 construction will follow as Federal funding becomes available.

Mainstream System

The combined sewer overflows from about 60 percent of the study area are captured by the Mainstream tunnels and conveyed to storage reservoirs. A collector system with drop shafts is used to collect the runoff from the overflow outlets and divert it to the tunnels. Basically, the system provides a free draining outlet for some 20 communities, portions or all of

Figure V-1 Tunnel and Reservoir Plan

Tunnel and Reservoir Plan as proposed by the Metropolitan Sanitary District of Greater Chicago.

which are located in the affected service area. However, system design does permit spillage in the North Shore and Main Chicago areas, but only if the most severe storms of record were to recur. The rate and volume, though, are controlled so that the spillage does not become a source of damage or pollution. Sufficient in-line storage is provided to avoid spillage in the area tributary to the North Branch of the Chicago River upstream of the North Shore Channel.

Some 56 miles (90 km) of Mainstream tunnels and extensions are required to convey the overflows to the terminal reservoir near the existing West-Southwest treatment plant. Plans call for the reservoir to be located in a commercial quarry about 2 miles (3.2 km) south and west of the plant. This reservoir will provide storage of 82,000 acre-feet (10,115 hect-m). In addition, an on-line underground reservoir adjacent to the existing North Side treatment plant has been provided. It controls only in-line back up and permits the use of smaller sized tunnels in the northern reaches of the Mainstream Tunnel. The room and pillar construction method will be used to create this 2,900 acre-foot (358 hect-m) storage area in the rock strata underlying the plant.

Calumet System

The Calumet system is not interconnected with the Mainstream system. It is an independent system serving some 14 communities, totally or in part. Slightly over 36 miles (58 km) of tunnels are needed to capture the overflow from a watershed that amounts to about 24 percent of the study area. The tunnels are sized to permit limited spillage to the Calumet River and Calumet-Sag Channel. However, spills will not be allowed into that portion of the Little Calumet River upstream of its junction with the Calumet-Sag Channel. The flows are conveyed to a terminal reservoir, also located in a commercial quarry. This quarry is located in Thornton, Illinois, several miles away from the Calumet treatment plant and will provide 39,000 acre-feet (4,811 hect-m) of storage. Part of the proposed tunnel system serves as an interconnector between the reservoir and treatment plant. The excavated rock will be stockpiled in the quarry and eventually incorporated in the future sales of aggregate limestone and for other uses.

Main (Lower) Des Plaines System

The excess overflow from the 19 communities interconnected with this tunnel system will be conveyed to the terminal reservoir that serves the Mainstream system, located near the West-Southwest treatment plant. No spillage will be permitted from the over 23 miles (37 km) of main-line tunnels and extensions. The applicable water quality standards, not the in-stream capacity, require this design constraint. Approximately 13 percent of the study area is located in the tributary watershed.

Northwest (Upper) Des Plaines System

This system will intercept sanitary and combined sewage flows arising within the Upper Des Plaines (O'Hare) Basin and divert these flows to the O'Hare Water Reclamation Plant (OHWRP) for treatment. The project includes all or parts of the communities of Arlington Heights, Buffalo Grove, Des Plaines, Elk Grove Village, Mount Prospect, Rolling Meadows and Wheeling and unincorporated areas in parts of the Townships of Elk Grove, Maine, Northfield, Palatine and Wheeling. Current plans call for the installation of 7.7 miles (12.4 km) of main-line tunnels and extensions. The tunnels are sized to prevent any spillage to the waterways of the excess runoff from the communities interconnected to the system. Water quality standards and in-stream capacity applicable to the receiving watercourses, Weller Creek and Feehanville Ditch, preclude any spillage. Also included in the system are two reservoirs: (1) an 850 acre-foot (105 hect-m) on-line surface reservoir at the upper end of the tunnel system; and (2) a terminal reservoir with some 2,700 acre-feet (333 hect-m) in storage capacity. Co-located with the terminal reservoir will be a new treatment plant. This plant will be used to process the flows from the surrounding, rapidly expanding suburban area. This action will help relieve the overload to the North Side plant which currently handles these flows.

PRESENT AWARD PROGRAM

The Tunnel and Reservoir Plan is the largest tunneling program in the history of the metropolitan Chicago area. The MSDGC has already awarded contracts for 47 miles (75.6 km) of rock tunnels ranging in diameter from 9 feet (2.7 m) to 33 feet (10.1 m), 137 drop shafts from 4 feet (1.2 m) to 18 feet (5.5 m) in diameter and the associated connecting structures,totalling

a bid price of $733,403,475. Additional contracts for an estimated cost of $376,679,924 will be advertized before the end of 1979. The breakdown for each area is given below.

Mainstream System

Contracts have already been awarded for 21.4 miles (34.4 km) of lined rock tunnels and 9.8 miles (15.8 km) of unlined tunnels 13 feet (4.0 m) to 33 feet (10.1 m) in diameters and 112 drop shafts with finished diameters varying from 4 feet (1.2 m) to 18 feet (5.5 m) and depths varying from 200 feet (61 m) to 266 feet (81 m) for a total cost of $543,633,595. These cover the first stage tunnels from 59th Street, near the proposed storage reservoir site, to Wilmette Harbour on the north end. Contracts have also been awarded for 128 structures connecting existing outfalls to the Shaft-tunnel system from Damen Avenue to Addison Street for a total of $46,094,860.

Construction work to be advertized by the end of 1979, for an estimated cost of $303,134,488 includes 6 miles (9.7 km) of lined tunnel and 2.4 miles (3.9 km) of unlined tunnel from 10 feet (3 m) to 33 feet (10.1 m) in diameter, 3 drop shafts, 4 feet (1.2 m) to 9 feet (2.7 m) in diameter, 82 connecting structures and a pumping station.

Calumet System

A contract for $79,256,370 has been awarded for 9.2 miles (14.8 km) of unlined rock tunnels varying from 9 feet (2.7 m) to 21 feet (6.4 m) in diameter and 17 drop shafts with finished diameters 5'-8" (1.7 m) to 15' (4.6 m) and depths varying from 249 feet (76 m) to 331 feet (101 m). This covers the section from Crawford Avenue to the Calumet sewage treatment plant.

The award program for the next year includes a pumping station for $53,400,000 and some 27 connecting structures at an estimated cost of $20,145,436.

Des Plaines System (Including both Upper and Lower)

All work for the Upper Des Plaines System is already under contract including: construction of 6.6 miles (10.6 km) of lined rock tunnels varying from 9 feet (2.7 m) to 20 feet (6.1 m) in diameter, 1.1 mile (1.8 km) of a 5 foot (1.5 m) diameter earth tunnel, 8 drop shafts, varying from 5 feet (1.5 m) to 9 feet (2.7 m) in diameter, 130 feet (40 m) to 150 feet (46 m) deep and connecting structures at some 29 locations. The contract price of tunnels and shafts is $59,820,000 and that of the connecting structures is $4,598,650.

No work is contemplated for the Lower Des Plaines system before 1980.